

CONTROL OF DIMENSIONS AND QUALITY OF WEFT
KNITTED FABRICS

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Control of Dimensions and Quality of Weft Knitted Fabrics

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The importance of accurately controlling loop length is discussed for various weft knitted structures. It is shown that consistent quality of jacquard fabric can be achieved by maintaining correct length ratios between certain base cells. While this really requires positive yarn feed control, a computer program is presented which can aid in eliminating the more troublesome cell types when positive feed is not available. The difficulties in feeding yarn into a weft knitting machine are examined through a model of yarn demand. This indicates the problems of existing positive and negative feed systems. Several positive feed systems based on the use of stepper motors are developed to various stages of operation. Some are successfully used on the knitting machine.

Abstract

The importance of accurately controlling loop length is discussed for various weft knitted structures. It is shown that consistent quality of jacquard fabric can be achieved by maintaining correct length ratios between certain base cells. While this really requires positive yarn feed control, a computer program is presented which can aid in eliminating the more troublesome cell types when positive feed is not available. The difficulties in feeding yarn into a weft knitting machine are examined through a model of yarn demand. This indicates the problems of existing positive and negative feed systems. Several positive feed systems based on the use of stepper motors are developed to various stages of operation. Some are successfully used on the knitting machine.

Terms and Definitions

Throughout the body of this work the textile terms used are those recommended by the Textile Institute¹. The terms used in connection with the electrical and electronic sections are those used by the Institute of Electronic and Electrical Engineers². For logic representation of circuits the American Military Standard³ symbols have been used because of their international acceptance. Where any deviation from these terms or definitions has been necessary it is clearly explained within the text. References are listed in the order in which they appear.

Contents

	page
Chapter 1 <u>Impressions of Weft Knitting</u>	1
1.1 General Introduction	2
1.2 Knitting Parameters	5
1.2.1 Yarn Input	6
1.2.2 Fabric Take-up	14
1.2.3 Needle Movement	18
1.2.4 Yarn	20
1.3 Fabric Production	22
1.3.1 Fabrics	22
1.3.1.1 No Needle Selection	22
1.3.1.2 Limited Needle Selection	25
1.3.1.2.1 Interlock Base	25
1.3.1.2.2 Rib Base	26
1.3.1.3 Jacquard - Full Needle Selection	27
1.3.2 Rib Jacquard Yarn Requirements	30
1.3.3 Knitting Jacquard Fabric	36
1.3.4 Knitting Data Presentation and Analysis	42
1.4 Conclusions	47
Chapter 2 <u>Yarn Movements</u>	49
2.1 Knitting Machine and Yarn Delivery Speeds	49
2.2 Model of Yarn Movement	51
2.2.1 Theory of Yarn Movements	51
2.2.2 Computer Implementation of Yarn Movement Theories	54
2.2.3 Single Knit	55
2.2.3.1 Results from the Basic Model	55
2.2.3.2 Introduction of Rob Back	57

2.2.4	1x1 Rib	59
2.2.5	Jacquard Structures	61
2.2.5.1	Effect of Machine Settings on Yarn Distribution	61
2.2.5.2	Comparison with Practical Results	64
2.2.5.2.1	Three Colour Results	64
2.2.5.2.2	Two Colour Results	66
2.2.5.3	Yarn Movement for Jacquard Units	70
2.2.5.3.1	The 1000 Unit	70
2.2.5.3.2	The 1100 and 1001 Units	71
2.2.5.3.3	The 1101 Unit	73
2.2.5.3.4	Combined Units	73
2.2.6	Feed Types and their Relationship with the Various Units	74
2.2.6.1	Negative Feeds	75
2.2.6.2	Positive Feeds	76
2.2.7	Modifications for Flat Bed Machinery	79
2.2.8	Effects of Timing and Cam Shape	80
2.3	Yarn Tensions within the Knitting Zone	81
2.4	Tension Measurements	82
2.4.1	Tension Variation	83
2.4.2	Tension Variations within a Single Cycle	85
2.4.3	Tensions on Flat Bed Machines	85
2.5	The Use of Positive Feed to Manipulate Yarn Distribution	86
2.6	Conclusion and Yarn Feed Requirements	88
Chapter 3	<u>Movement Control Mechanisms</u>	90
3.1	Stepper Motors	93
3.1.1	Variable Reluctance Stepper Motors	94

3.1.2	Permanent Magnet Stepper Motors	95
3.1.3	Hybrid Stepper Motors	95
3.1.4	Performance of Stepper Motors	97
3.2	Coil Switching	98
3.2.1	Unipolar R/L Drive	99
3.2.2	Bipolar R/L Drive	100
3.2.3	AC Synchronous Drive	102
3.2.4	Current Regulated Drives	102
3.2.4.1	Dual Voltage Supply	103
3.2.4.2	Variable Voltage Supply	103
3.2.4.3	Chopper Drive	103
3.2.5	Transistor Selection	104
3.2.6	Protection Circuits	105
3.2.6.1	Diode Protection	105
3.2.6.2	Suppression with Bifilar Wound Motors	106
3.2.7	Comparison of Motor and Drive Combinations	106
3.3	Generation of Stepping Sequences (Translation)	109
3.3.1	Microprocessor Control	109
3.3.2	Hardware Control	110
3.3.2.1	Digital Motor Logic Circuit (DML)	110
3.3.2.2	SAA 1027 Stepper Motor Drive Circuit	111
3.3.2.3	CMOS and TTL Circuits	111
3.4	Pulse Generation and Control	113
3.4.1	Oscillators	115
3.4.1.1	555 Oscillators	115
3.4.1.2	555 Oscillator with Ramping Control	116
3.4.1.3	555 Oscillator used as a Phase Locked Loop	118

3.4.2	2240 Programmable Timer	118
3.4.2.1	Harmonic Locking of the 2240	119
3.4.2.2	2240 as a Phase Locked Loop	120
3.4.3	Voltage to Frequency Conversion	120
3.4.5	Purpose Built Motor Control Circuits	121
3.4.4.1	Ramp Control Oscillator (RCO)	121
3.4.4.2	Ramp Control Logic (RCL)	122
3.4.5	Microprocessor Pulse Generation	123
3.4.5.1	Direct Loading of the Input/Output Port	124
3.4.5.2	Parallel In, Serial Out Facilities on the Output Port	125
3.5	Commercial Drive Boards	126
3.5.1	Unipolar R/L 053/1	127
3.5.2	Bipolar R/L LD2	129
3.6	Microprocessor Systems for Motor Control	131
3.6.1	Single Motor Control	133
3.6.2	Dual Motor Control	133
3.6.3	Knitting Considerations	134
3.6.4	Pulse Generation from Parallel In, Serial Out Register	133
3.7	Motor Small Cycle Performance	140
3.8	Hardware Control Systems	145
3.8.1	External	145
3.8.2	Needle Selection	147
3.8.2.1	Toggling	147
3.8.2.2	Timing	149
3.8.2.3	Utilising Slewing of the Motor	150
3.9	Conclusions and Possibilities	153
Chapter 4	<u>Applications of Yarn Movement Control on Knitting Machines</u>	154

4.1	Length Control per Needle	154
4.1.1	Applications on a Circular Machine	155
4.1.1.1	Single Step	155
4.1.1.2	Multiple Step	156
4.1.2	Considered Application on a Fashioning Machine	156
4.2	Flat Bed Machine	157
4.2.1	Microprocessor Controlled	158
4.2.2	Hardware Controlled	161
4.3	Jacquard Feed Systems	165
4.3.1	Circular Machine	166
4.3.2	Proposed Development on Circular Machine	168
4.3.3	Flat Bed Machine	170
4.4	Take-up Control	174
4.5	Matching Actual Yarn Demands	176
4.6	Conclusions to Knitting Considerations	177
Chapter 5	<u>Conclusions</u>	178
	<u>References</u>	181
	<u>Appendices</u>	189

Chapter 1

Impressions of Weft Knitting

Over the years the progressive increase in production rate of weft knitting machinery has made the use of weft knitted fabric very popular in certain market areas. In the underwear market the cost of fabric production, plus the easy fit properties of weft knit structures, make this type of fabric ideal. This is also true in the legwear area. For casual outerwear the weft knit is still extensively used in the traditional market of cardigans and pullovers. Its strength here is due not to production rate but to the possibility of shaping and patterning garments, many of these being produced on the low production rate flat bed machines.

Weft knitted fabric has, however, little value and limited use in other areas. This is basically due to the inability to correctly control the dimensions and the stability of these dimensions within the fabric. This is especially apparent in the area of patterned fabric. Even though it has become easier to produce needle selection fabrics due to developments in the use of electronics, the basic dimensional problems still exist.

To produce a satisfactory fabric the finished dimensions must be known, the physical properties must be predictable, the cost must be reasonable and it must be easy to produce. Obviously weft knits are primarily important because of cost and ease of production. The markets open are only those in which fabric stability primarily is not critical. It is due to lack of control and understanding of the knitting process that this difficulty exists. To extend or even

maintain the market for weft knits this must be improved. A satisfactory fabric requires that four major factors in the knitting process be controlled. These factors are the needle movement, yarn length input, yarn properties and fabric take-up.

The aim of this work is in four stages, related in importance to the production of a satisfactory fabric and the overcoming of deficiencies in existing systems:-

1. To adequately control yarn feed for all structures.

2. To present fabric in a known state which can be easily finished to a quasi-stable and predictable position.

3. To reduce knitting stresses on yarn.

4. To reduce stresses on the knitting machine and knitting elements.

To achieve any of these aims the previously mentioned major factors must be controlled.

1.1 General Introduction

Attempts to rationalise the properties of knitted fabric commenced early in the twentieth century⁴. It was, however, not until the forties and fifties that real progress was made. At that time extensive investigations of the dimensions of knitted fabrics were carried out⁵⁻⁹. It was, however, the work of Pierce^{10,11} on the geometry of fabrics which led to the developments of the fifties¹²⁻¹⁵. This work used the basic knitted loop as the starting point for all analysis. It was predicted that if this basic unit of the knitted fabric could be solved for its properties then all the weft

knitted fabric's properties could be deduced. By the sixties two different paths had emerged. These were those which led to the work based on practical studies of knitted fabric dimensions¹⁶⁻²⁰ and those which used mathematical means to solve the knitted loop²¹⁻²⁴.

The practical studies are basically built upon observation of the fabric dimensions for a given loop length or length of yarn per needle. This work established that there are fairly constant ratios between loop length and wales per unit length, loop length and courses per unit length and loop length and the stitch density squared¹⁶⁻¹⁸. Expressed simply this means that the loop has a constant shape and the size is only dependent upon the yarn length. This work was primarily carried out upon plain knit fabrics but was later extended to simple two bed structures^{19,20}. For the two bed structures the length is expressed in terms of the cellular or repeat length within the fabric. To compare results for different fabrics a unit of average length per knitting needle is used with the averaging taking place over the number of needles in the cellular repeat. These observations have been of some interest to knitters.

Perhaps the most difficult problem has been in assessing the effect of yarn thickness. It would be expected that this would have a large effect upon the loop dimensions but the practical studies lead to the opposite conclusion. A concept of cover factor or tightness factor has been used in which the relationship between the yarn diameter and yarn count²⁵ has been used. The ratio $K = \sqrt{\text{Tex}} / (\text{loop length})$ was used to successfully compare the properties of fabrics made from yarns of different weight. Here little effect upon the

dimensions was found, although other studies have shown that this parameter relates well to physical performance of the fabric²⁶⁻²⁸. By examining the diameter of the yarn in the fabric it was found^{22,29} that there was a tendency for the diameter of the yarn to vary depending on the space available.

The more mathematical approach has concentrated on solving equations for the loop and the network of loops which make up the knitted fabric. These studies progress little beyond the plain fabric. Early work concentrated on a geometrical solution^{11,12} while later studies began to look more at the forces involved^{21,23,24}. Developments of this work have led to computer techniques³⁰⁻³⁶ which have enabled some performance of the fabrics to be predicted^{26,37}. While many people have worked in this area using a wide variety of approaches, the prime agreement is that the loop length will ultimately determine the fabric's properties for a given yarn.

However a problem does exist even within this basic concept. While a fabric is being knitted it often has its loops considerably distorted from the "relaxed" dimensions. To achieve relaxation of these stresses the yarn must move within the structure. It has been shown for double knits²⁹ that it is often necessary to go to extreme lengths to achieve this relaxation. Here a series of washing and dry cleaning treatments well beyond any commercial finishing process was used to achieve relaxation.

Most of the successful studies on fabric dimensions have concentrated on wool as the base fibre³⁸⁻⁵⁰. The properties of the wool fibre, especially its "natural resilience", are of prime importance in producing a relaxed fabric.

Studies on cotton have seemed to be more confusing with the difficulty in relaxing fabrics contributing to the varied results^{40,51,52}. It is when the natural fibres are not used that the problem becomes acute. Nylon⁵³ and acrylic^{54,55} fibres have shown conflicting trends and present extreme difficulty in relaxing to unique dimensions. These comparative effects of wool and synthetic fibres can be seen most clearly in the warp knitting case. On the warp knitting machine, by manipulating tensions, fabrics can be produced well away from a relaxed state. Here studies on wool fibre and filament yarns^{56,57} have shown that while the wool fabrics can be brought to unique dimensions the filament fabrics in many cases maintained a knitting based history.

While the length of yarn within the structure is undoubtedly the most important parameter to be controlled in knitting, it is necessary also to control the other major factors ; the needle movement, yarn properties and fabric take-up, to ensure that a fabric is reproducible^{58,59}. All the major factors will affect the shape the loop initially takes up within the fabric and any variation in this will have to be removed in finishing.

1.2 Knitting Parameters

An examination of the means of controlling the knitting factors of yarn input , fabric take-up, yarn type and needle movement is necessary so that their relative importance can be determined.

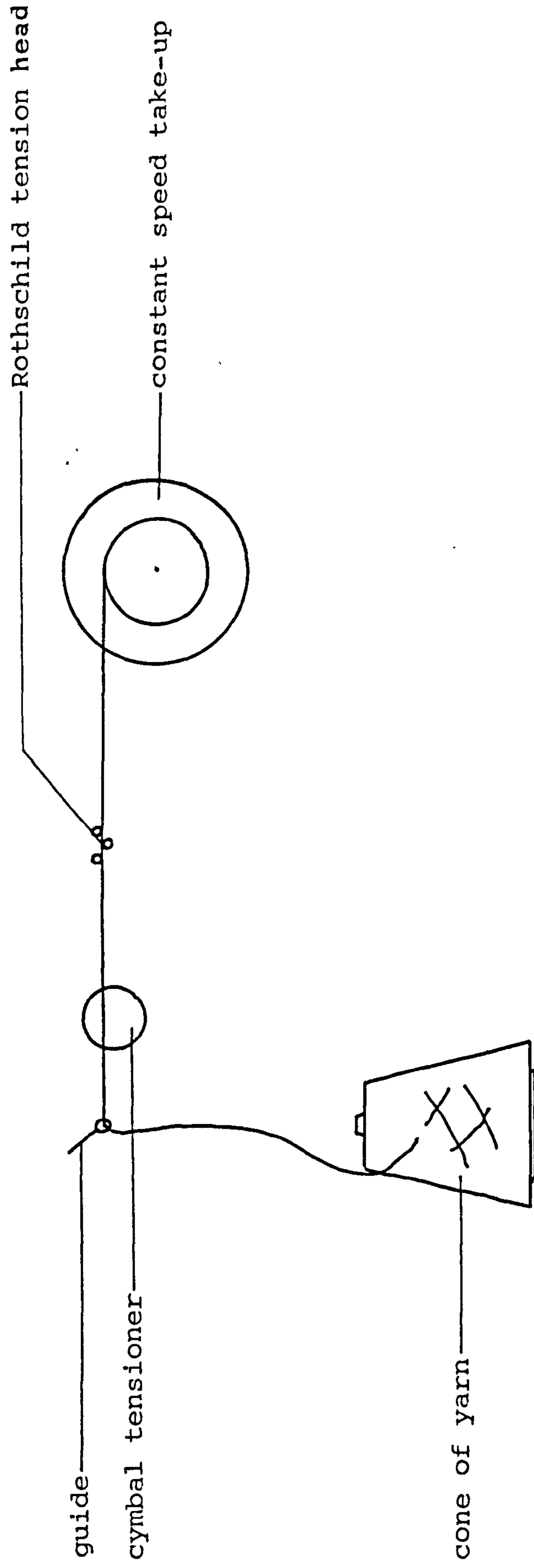


Figure 1.1 Experimental arrangement for measuring the tension of yarn as withdrawn from a cone.

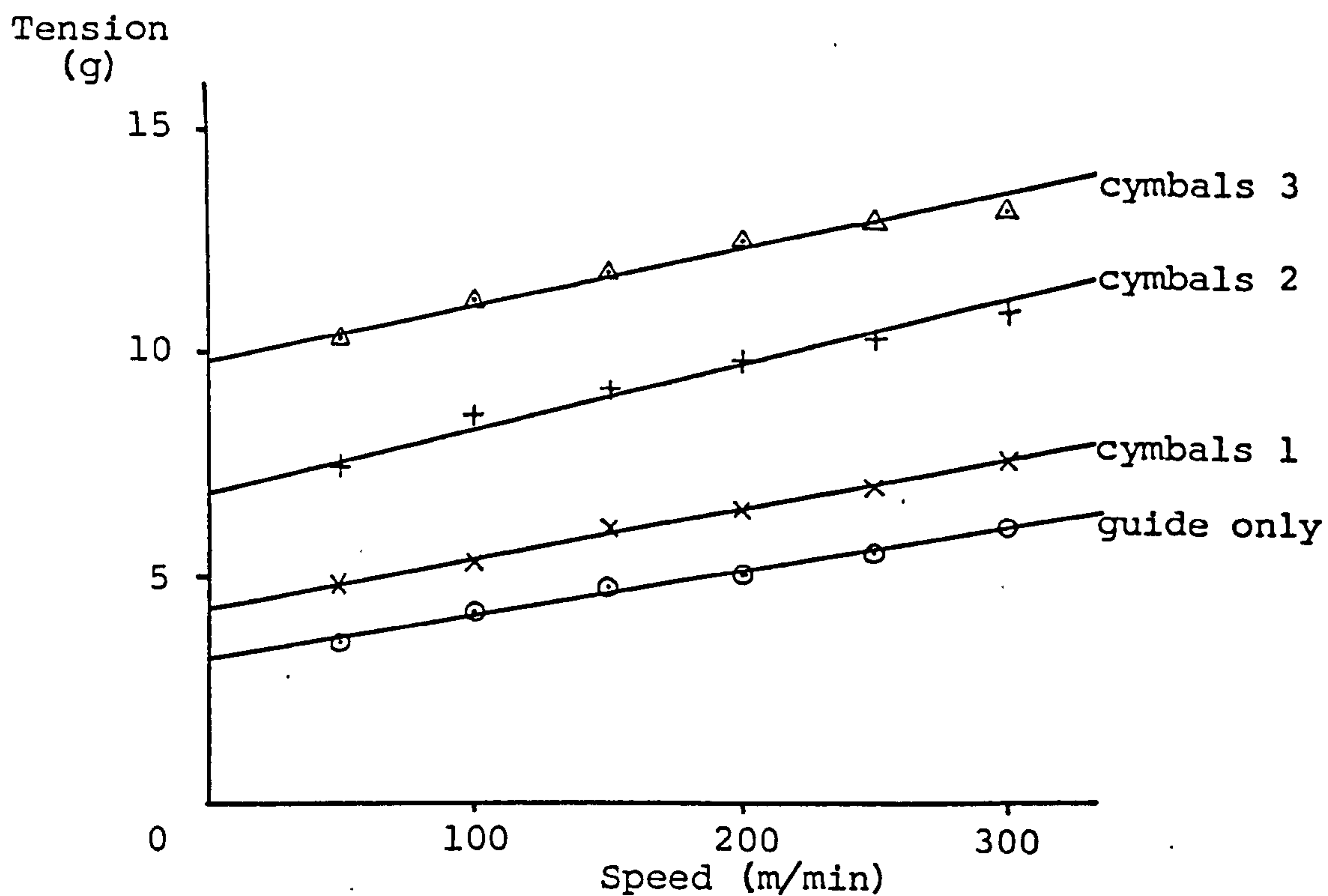


Figure 1.2 Tension v. speed for drawing yarn off a cone.

Table 1.1

Tension variation with speed for 150 denier textured polyester yarn drawn off a cone.

	gradient (g min /m)	intercept (g)	correlation coefficient
guide only	0.009	3.25	0.9937
cymbals 1	0.011	4.36	0.9984
cymbals 2	0.014	6.93	0.9926
cymbals 3	0.012	9.97	0.9867

1.2.1 Yarn Input

The control of the length of yarn taken into the knitted fabric requires that both the length and the tension (and hence extension) at delivery of the yarn must be controlled. Weft knitting has a considerable advantage over other means of fabric production in that no special yarn preparation is required. A fabric can be formed off a single cone of yarn. The nature of the withdrawal from the cone must be understood in order to understand the input of yarn to the knitting machine. For the system in which the yarn is drawn off from a cone through a guide above it, the tension will vary with speed. Using the experimental arrangement shown in Figure 1.1, the nature of this withdrawal can be investigated. Here the yarn was pulled from the cone at various rates and the tension measured after passing through the single guide. The measurements were taken using a Rothschild tension measurement system⁶⁰ in conjunction with the Rothschild take-up device as employed on the F-meter⁶¹ to provide a variable speed drive. The results from this series of experiments are given in Appendix 1, along with Table 1.1 and Figure 1.2. As well as the results for drawing directly from the cone through a guide, those found using a cymal tensioner⁶² at various settings are shown. Here it can be seen that increasing the speed of drawing the yarn off the cone increases the tension of the yarn. All the curves show similar straight line forms in the speed range used (that commonly encountered in knitting) with a slight increase of slope with tension setting with speed and a general shift of the whole curve upwards with increased setting.

Various other tensioners^{62,63} can be used but the above variation is fundamental to the withdrawing of yarn from a cone⁶⁴⁻⁶⁸. The tensioners can be considered to be of two general types: those which act to multiply the input tension and those which add to the input tension. The first type can be used to remove crimp from the yarn or to move the yarn to a section of its load-extension curve where an increase in load gives little increase in tension. (The load-extension behaviour of common knitting yarns is given in Appendix 2.) This of course has no effect on tension variations. The second type aims to reduce the variations either by increasing all the tensions by a fixed amount or by increasing low tension points by more than high tension points. At least this will give a flat tension with speed response but at the maximum tension of the incoming yarn.

In early knitting systems the yarn feed was separated from the loop forming process⁶⁹. The yarn was fed as sinker loops formed across the fabric width. This prepared length was then taken into the loops by knocking over all the needles simultaneously. This system remains on some full-fashioning machines⁷⁰ which incorporate bearded needles for ease of garment shaping. A similar system is used in knitting from pins (hand knitting). Here the length is prepared by wrapping the yarn around a pin and this prepared length is then turned into a loop. These systems, where yarn feed is separated from loop formation, have good length control properties but do not control the tension of the yarn. They are also extremely slow as two movements are needed; one to prepare and the other to form the loops.

These movements are carried out sequentially.

Perhaps the single most important factor which has led to the increase in production of weft knitting machines is the development of the individually moved latch needle⁷¹. The knitting process then becomes, rather than separate actions to feed yarn and form loops, a single action. The needles across (or around) the machine are successively moved, drawing in the yarn and hence forming the loops. While this process dramatically increases the production rate of the knitting machines by incorporating yarn feed and needle movement into one action, a certain loss in control of yarn feed occurs. The loop forming method makes the yarn drawn extremely dependent on the movement of the yarn off the cone. The needle movement becomes very critical and yarn friction becomes vitally important in determining the tension at the knitting point and hence the yarn length drawn⁷²⁻⁷⁴. Thus for good yarn length control it is not satisfactory to just pull the yarn off the cone.

Positive yarn feeds have existed in some form since the early twentieth century. Early systems were used on the bearded needle sinker wheel machines in a similar form to the sinker controlled feed of the early flat machines⁴. Here a pair of intermeshing gear wheels helps prepare the yarn to be fed. There is, however, no positive nip on the yarn and so the system is really an assisted feed rather than a fully controlled feed. With the engineering developments of the thirties and forties leading to the emergence of the multifeed machine, the problem of yarn feed became more important. While the fabric is made off only one cone the friction characteristics within a single piece remain constant

but when many cones are used individual differences result in a striped fabric (barré). This becomes extremely apparent in plain fabrics. This phenomenon led to the improvement of positive feeds.

Early developments by the Hosiery and Allied Trades Research Association (HATRA) used a nip roller drive system placed between the cone of yarn and the feed point. Each feed was provided with an individual roller pair^{75,76}. The introduction of the trip-tape system⁷⁷⁻⁸⁰ meant that only a single drive unit was needed to feed to all stations. Here a single expandable pulley is used to drive a tape which in turn is used to drive the yarn at each feed station. This ensures that equal drive rate is achieved at each feed and reduces the drive complexity for high numbers of feeds. The yarn at each drive point is nipped between the tape and a dummy roller. Both these types of drive provide a continuous feed at a speed proportional to the speed of the machine. Up to six rows of tapes can be provided on a single machine, enabling a selection of different feed rates at different feeders. Here it is important to stress that the yarn is provided at a constant speed to the knitting point.

Again the yarn length fed is separated from the needle movement, except that both actions occur simultaneously. The needle movement is now used to control the tension at the knitting point, to ensure that yarn is knitted into the fabric and to distribute the yarn within the structure. A straight nip drive has problems with variation or "snatch" off the cone which can be transferred through the drive system^{81,82}. Some developments have taken place in which,

by not nipping the yarn but by driving it by means of a multi-wrap capstan off the cone, variations of this type are reduced^{78,83}.

When elastic is to be fed, undoubtedly the yarn drive becomes critical. Positive feed for elastic on sock machines has been extensively used. Here the drive must combine control of length and tension. Generally in this application elastic is only laid in and so lies straight in the fabric instead of forming loops. Tension regulated positive feed has also been attempted but as yet has not appeared commercially⁸⁴.

Positive feed on circular machines undoubtedly does a great deal to improve the consistency of the fabric produced. However, perhaps the most important factor in assuring the success of positive feed relates to its effect on tension. Because the driving point is isolated from the needle movement it is possible to keep the actual tension on the yarn as it enters the knitting zone very low. This means that much weaker yarns may be utilised in knitting without producing problems of "knittability".

On flat bed knitting machines the feed problems are escalated considerably by the fact that allowance must be made for the movement of the cam carriage. In this system the actual point where the yarn enters the fabric moves relative to the stationary cone. One method of overcoming this problem, so that a constant speed of feed can be used, has been attempted by HATRA⁸⁵. A reciprocally moving dummy carriage is provided which compensates for any cam carriage movements. This type of system however has considerable edge effect problems and greatly increases mechanical

complexity of the knitting machine. On most flat bed machines a dual cam carriage system (two feeds) is used, so it is only necessary to control the movement of two yarns at a time. As the fabric is produced off fewer cones, differences between the yarn fed off mixed cones can be minimised. However, when the same fabric is produced on two machines, or even successively on the same machine, considerable variation can occur, especially in the case of striped fabric.

The flat bed machine offers advantages over circular machines in terms of patterning and shaping, although the production rate is much lower. The inadequate feed, however, acts as a huge drawback for this type of fabric production.

A feed development based on a different system has helped to improve the quality of flat knitting. This is a constant tension feed. By incorporating a rewinding or active device between the cone and the knitting point it is possible to considerably improve the input properties over those directly off the cone or through conventional tensioners. This is a storage feed⁸⁶⁻⁸⁸ which winds the yarn onto a drum from the side. The yarn is then drawn off the end of the drum with the tension controlled by a ring with small plastic fingers. The device automatically takes on more yarn when the store is reduced to a pre-set level. This device was originally developed for shuttleless weaving machines, where yarn must be delivered in short bursts at minimum tension, but has proved very successful on knitting machines. When the experiment of drawing yarn off the cone is repeated through this device, its effect can immediately be seen. Results using the Rothschild tension measuring

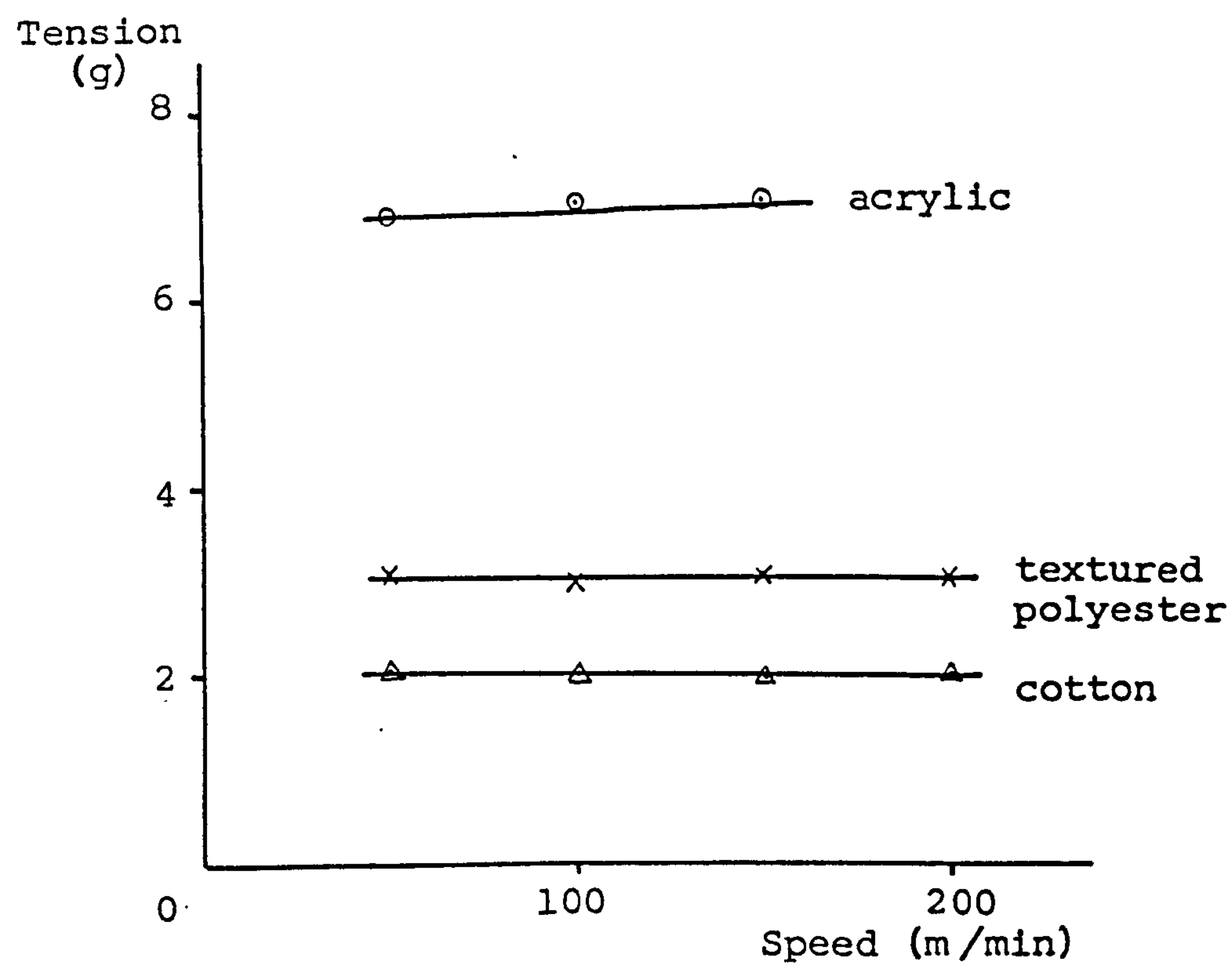


Figure 1.3 Tension v. speed for various yarns through the IRO unit.

Table 1.2

Tension values for various yarns through the IRO unit over a normal knitting speed range.

Yarn	Tension (g)	Speed Range (m/min)
acrylic	6.99	50-150
cotton	2.00	50-200
textured polyester	3.05	50-200

device as previously described but through an IRO storage feed are given in Appendix 3. These results are tabulated in Table 1.2 and shown in Figure 1.3 as a plot of tension against speed. It can be seen that the delivery tension is independent of speed in the range used (that of normal knitting speeds). This means that this device, when used on a flat knitting machine, can eliminate effects due to speed differences of the carriage mechanism when it moves in each direction. Also the unit provides a means of feed for patterned fabric. The feed rate for patterned fabric is dependent upon the pattern and the IRO provides a means for at least providing the yarn for various pattern units under the same tension. However this system does not help a great deal when using yarns with different frictional properties, as the tension build-up within the knitting zone will still affect the actual loop length. At present though, this offers the only commercially acceptable feed control for fabrics requiring variable feed rates.

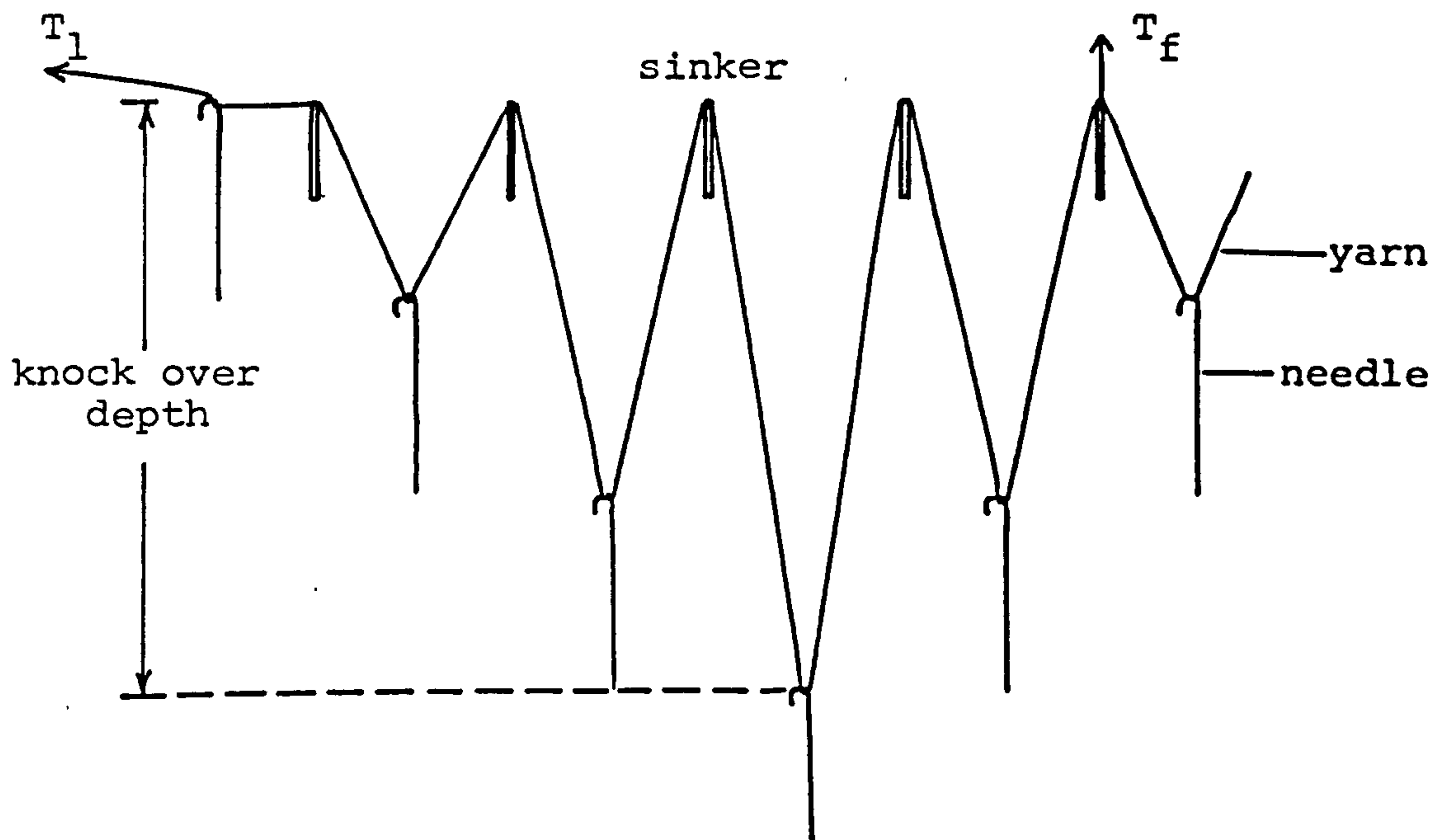
One area which has received some study is that of intermittent feed rates as found on legwear machines. The simplest of these developments uses a standard trip tape arrangement to feed the leg of the sock and then takes the yarn out from under the tape (and hence stops feeding) during the formation of the heel. An alternative uses a stick-slip friction drive which again can be set to drive or slip⁸⁹. Electric motors have also been proposed as a means for controlling the feed on legwear machines but at present have not been developed commercially⁹⁰.

In other areas of fabric production (weaving and warp knitting) positive feed methods developed earlier, primarily

due to the need to drive heavy warp beams. In both these cases the fabric is produced in full width with the yarn fed at a constant or tension controlled speed. The cyclic movement of the machines is compensated for by means of a spring loaded or even driven bar. In weft knitting it has not been necessary to compensate between the constant feed and the intermittent cyclic fabric formation. Here there is very little displacement of the fabric forming elements and so any length variation is taken up by yarn extension or yarn movement within the knitting zone. This will of course cause cyclic yarn feed variations from needle to needle even on plain fabrics.

To satisfactorily control the yarn length fed, the amount of yarn delivered must be matched with the fabric's yarn requirements for the repeat within the fabric. While this can be achieved with a constant feed system for plain fabrics, where any needle selection takes place the knitting performance of the system drops considerably. Obviously the feed rate required is related to the needle selection within the structure. Constant speed feed, however, can only feed to the average demand within the repeat. It must be possible to match the actual feed to the individual loop forming at any needle. This may be considered as the yarn demand within the knitting zone. Even with plain fabric a constant speed feed will not feed to the actual yarn demand but only to the average yarn demand per needle.

Thus it is at present not possible to control the length of yarn fed to any but the most simple of fabrics and even for these not at the optimum knitting conditions. With patterned fabric or any fabric produced on a flat bed



$$T_1 e^{uG} = T_f e^{u(B-G)}$$

where T_1 = input tension

T_f = tension due to take-up

G = angle of wrap at maximum tension (balance point)

B = total angle of wrap

so

$$G = (Bu - \log_e(T_1 / T_f)) / 2u$$

giving the maximum tension;

$$T_{\max} = T_1 e^{uG}$$

Figure 1.4 Balance of input and take-up tensions in the knitting zone.

knitting machine, constant tension feed offers the best available solution . While this may make it easy to produce the fabric, it does not set the loop length at the required value, this still being determined by the yarn characteristics.

1.2.2 Fabric Take-up

The length of yarn drawn into the fabric is determined by a balance between the input and output tensions applied during loop formation. The output tension is applied by the fabric take-up system. If the needle movement is examined, as shown in Figure 1.4, the balance between the input and the take-up tensions can be calculated to be at a specific point within the system. It has been found^{74,91} that in a symmetrical knock-over, lifting cam situation, the length of yarn held on the needle at this point on the cam will be the amount of yarn which remains within the structure on this needle when it leaves the knitting zone. This was found for single knit fabric. Although the actual situation has been some what simplified, some understanding of the tension build up in the system and the relative effects of yarn and fabric tension together with yarn friction can be seen⁹². The greatest problem with this analysis lies in deciding the point of applied take-up tension and its value compared with the average fabric tension. Obviously it is the localised tension at the knitting point which is important but, due to its distance from the take-up rollers where the tension is applied, it is difficult to control. This difficulty will increase when patterned fabric is produced where the loops are held on the needles for different times as determined by the pattern.

If the yarn input is positively controlled then a limit is imposed on the system. Under these conditions it has been found that the finished dimensions of the weft knit are essentially independent of applied take-up tension^{19,49,50}. This relies on the fact that relative yarn movement within the structure can be achieved in finishing. This, however, is not always the case^{30,40,51}. Care must be taken with the setting of the take-up tension to ensure that the loop is not taken to a point where relaxation becomes difficult. The level of the tension in the positive feed case will also set the maximum tension developed in the yarn and hence the knittability.

The take-up requirements of the knitting action are twofold: the needle must be free to rise without lifting the fabric and the formed loops must be cleared from the needle. Existing take-up arrangements fall into two types: those which aim to maintain constant fabric tension and those which constantly drive the take-up rollers. On circular machines with rotating cylinders a constant rate drive of take-up is generally used. Here a common system⁹³ uses a cam cut on the circumference of the machine to drive duplicate ratchet wheels on either end of the take-up rollers. The draw of the ratchet is controlled by springs which can be set. The fabric must be firmly gripped by the take-up rollers and so a high pressure is exerted on the fabric. This crushing action can cause permanent damage on the folds in the fabric.

Considering the situation on a circular machine, it can be seen that the fabric is formed in a circle but is wound up in a straight line. The collapsing of this initial

tube into a double layer of flat fabric must be carried out in as controlled a manner as possible to stop local distortions in the fabric⁹⁴. A spreading arrangement aims to minimise tensions around the circumference. The setting of the spreader is critical and usually difficult to accomplish⁵². The biaxial loading of weft knit fabric has been studied to some extent to examine the effects of various load arrangements^{95,96}. This however does not help to actually set the arrangement on the machine.

A revised system has been developed⁹⁷ which gives a much more flexible adjustment. Here the aim is to equate the path lengths from various points on the circumference. While this has led to some improvement, it is difficult to imagine any system, other than one applying the take-up force from the circumference of a circle, successfully controlling this variation around the machine.

Constant tension take-up methods on circular machines offer no distinct improvement in this tension spread. They are generally used on rotating cam-box machines where body lengths, which require varying take-up rates, are produced. The tension is either applied from a balance system or by means of a constant torque electric motor arrangement.

On flat knitting machines, where positive feed does not exist, take-up is very critical and is generally applied from full width rollers. The take-up conditions vary greatly across the machine, the tension being dependent upon the cam carriage position.

Several methods have been used to ease the take-up problems by reducing the need to apply tension at the knitting point from the take-up rollers. One function of the take-up

is to hold the fabric down as the needles lift and this can be taken on by another element. This means that the take-up rollers need only apply enough tension to remove the formed loops from the needles, which is less critical in the loop forming process. Holding down can be provided by sinkers in the single knit case. However, this becomes difficult due to lack of space on a two bed arrangement.

A technique using a small rod to hold the fabric down has been successfully applied on flat machines and this again means that the tension from the take-up rollers is less critical. This device is known as a presser foot⁹⁸⁻¹⁰⁰. Not only does it reduce take-up tension variation but allows for multiple tuck effects and simple shaping of garment panels. On circular machines a similar device has been used¹⁰¹ but as yet has not seen commercial development. Compressed air has also been used to carry out the holding down action¹⁰². Both these methods were shown to considerably reduce the distortion of the loops on the knitting machine and led to much easier relaxation of the fabric.

In warp knitting the rate of take-up is used to control feed on negative feed machines (especially Raschel knitting). Here the balance between the beams is adjusted at the let-off or yarn feed end, while the actual loop length is controlled from the take-up rollers. The machine is provided with gears calibrated to give a known number of courses per linear length of fabric. This calibrated take-up is also provided on weaving machines. On weft knitting machinery, however, it is rare to have any calibration of the take-up. In the positive feed case the effects of take-up are small, as long as care is taken to limit excessive tension in the

knitting zone. For the negative feed case, as found in patterned fabric or on flat bed machines, the take-up will have a marked effect on the fabric. Either considerable improvement of the present systems or positive yarn control must be introduced to produce consistently satisfactory fabric.

1.2.3 Needle Movement

It is the movement of the needles which controls the fabric formation. In the case of the popular latch needle⁷¹, the needle must be lifted so that the previous loop is below the latch. The needle is then lowered, drawing yarn through the old loop to form the new loop and casting the old loop off. Needle selection is effected at the lifting point. Because of the high speeds of knitting machines, the needle must go through extremely rapid accelerations. Thus any needle movement elements must be so designed as to control the needle while loading it to the minimum extent. Within the knitting zone, when the new loop is being formed, the needle is controlled by the knock-over cam and the shape of this cam is most important. A balance must be chosen between high angles, which give less needles in the knitting zone and hence less tension build-up in the yarn and also enable more feeds to be inserted, and low angles for which the load on the needles will be less^{103,104}. It has been found that the forces on the needle are linear with machine speed and exponential with cam angle^{105,106}. Theoretical and practical studies of the tension build up and needle loading have led to the development of non-linear cams^{74,92,104,108-111}. These cams make much higher machine speeds possible. The

importance of full control on the needles and its effect on consistency of loop formation has also been demonstrated through studies of the forces on the cams¹¹²⁻¹¹⁴. It is necessary to be able to move the cams in order to set them for different loop lengths.

On a two bed machine the relative movement of the needles from each bed is very important. To control the loop formation relative timing changes can be used, as can the separation of the needle beds. By appropriately setting the timing a method of using only one bed to draw in the yarn, with the other bed to distribute the yarn, results in the formation of very small loops giving a tight stable fabric.

Negative feeding means that the needle movement is also responsible for the control of the loop length. This means that relative settings of cams between the various feeds is critical. With positive feed this problem is removed but cam setting will influence the actual tension on the yarn and so is still important.

The needle movement control on knitting machines is generally extremely good. High precision engineering techniques usually make it quite easy to set up the machine. Problems arise more from care for the needles and identifying any damage in them. Optical scanning techniques¹¹⁵ enable the needles to be examined while the machine is in motion and stop the machine if any damage has occurred.

The contribution of the yarn tension to the loading of the needles is still in the hands of the knitter and dependent upon controls of the yarn input and fabric take-up. Under conditions of negative feed very little control over

these factors is offered, especially in the area of patterned fabric where loading will vary on different needles.

1.2.4 Yarn

Yarn properties are a factor which is not controllable by the knitter and knitting machine builder and, as such, must generally be something of an unknown. It is desirable on any knitting machine to be able to use a wide variety of yarn types. There is the obvious limitation of yarn diameter in relation to needle hook size but this is probably the only physical restriction. However, any yarn varies considerably even in this basic parameter^{116,117}.

The yarn properties which are most important to the knitter are the friction^{72,74} and the load-extension relationship¹¹⁸⁻¹²⁰. Friction, in the negative feed case, is often considered to be the most important yarn parameter. However, prediction of yarn friction and its relationship to knittability is not easy. Friction measurements are generally taken under conditions far from those encountered in knitting. The effect of variations of angles of contact, diameter of bollards and speed are not predictable in terms of present yarn friction models¹²¹⁻¹²³.

Positive feed goes a long way towards enabling consistent knitting where friction varies. As it is not available in all knitting situations, further development would seem to be most important.

The problems appear at their worst, perhaps, in patterned fabric. Here, in the case of fine gauge circular machines, there is a certain reluctance to use weak yarns. Textured polyester is an extremely strong yarn and so is commonly

used in this area where the variable stress on the yarn makes accurate prediction of yarn property requirements difficult. Textured polyester is, however, far from desirable in terms of garment comfort and appearance. The weaker yarns, such as wool, which offers much more desirable garment fabrics, are neglected by the knitter because of the difficulties involved in knitting.

Flat bed jacquard machines are at present going through a period of considerable development with the widespread introduction of electronic needle selection^{124,125}. The feed is again negative and so strongly dependent on yarn properties. This leads to the undesirable situation in which yarn is chosen for its knitting properties instead of the resultant effects in fabric and garments. The desirable properties of a knitted fabric are a soft and full handle and appearance. This is easiest to achieve with low twist yarns. Often, however, higher twist, smoother yarns are used to reduce knitting problems, with a resultant reduction in desirable fabric properties.

Development work must concentrate on the area of yarn feed which will lead towards making knitting much less limited by yarn properties. This in turn will allow the machine-made knitwear designer to utilise the desirable properties of the knitted fabric without the restrictions of knittability as they now exist.

1.3 Fabric Production

Having considered the effect of and the ability to control the various knitting parameters it is important to consider these in relationship to various fabrics. How the control information can be determined and then used to regulate the various functions is vital for any knitting developments. While this work will concentrate primarily in the area of rib jacquard fabric much valuable information from studies of the simpler fabrics can be used.

1.3.1 Fabrics

The actions possible on the weft knitting machine are knit, miss, tuck and transfer. The fabrics considered can be divided into three basic groups : no needle selection, limited needle selection and full jacquard selection.

1.3.1.1 No Needle Selection

For these fabrics each needle knits on each course. The fabrics produced are plain on one needle bed and 1x1 rib on two needle beds.

The plain fabric is by far the most studied^{14,16,21,23,24,26,29,31,33,34,40,49,95,96} and best understood in terms of physical properties, as well as being the simplest to produce. The knitting machinery used to produce this type of fabric runs faster than any other. Plain fabric should represent the starting point for any investigation into knitting. While the needle movement is extremely well controlled, to allow the high needle speeds, some problems still exist with yarn feed. It is on this type of machine that needle movement, loop formation and machine loading

studies have been carried out^{74,92,103-114}. Constant speed positive feed is used for plain fabric to control the yarn at the speeds required while still maintaining a low tension. However, the demand due to the needle action is not constant within the knitting zone^{127,128}. The difference between supply and demand is taken up by extending the yarn. To maintain control of the yarn it must always be kept under tension. If yarn delivery were matched to needle movement it would be possible to maintain yarn feed tension constant and hence reduce maximum tension. Fabric take-up for this fabric seems to be adequate. It is generally produced with the aid of holding down sinkers, and so the force applied from the fabric take-up rollers can be kept low. The take-up rollers are used primarily to clear the fabric from the needles.

To produce 1x1 rib two needle beds are required; hence the machinery to produce this fabric is more expensive. The fabric is also much less stable than the plain fabric and so is not as useful commercially. Studies on the dimensional and structural properties of the 1x1 rib have been extensive^{6,34,37,38,48,50,117,129,130} but have not included loop forming on the machine. Feeding yarn to form the fabric is somewhat complicated by the need to rapidly cross over between the needle beds. Because of these cross overs between loop forming elements the fabric is formed on the machine in a state very different from that of a fully relaxed fabric. Relative yarn movement is usually required in this type of structure to enable full relaxation of the loops. Here there is also difficulty in producing tight fabric due to the cross overs. Tighter fabric can be produced by off setting

the cams on each bed. This allows the first cam to draw the yarn into the structure with that on the other needle bed redistributing the yarn without drawing more yarn into the structure. This non-synchronised timing is used extensively on two bed knitting machines.

The take-up on rib machines is also more critical, as the interlocking of alternate needles from each bed means there is no space to use sinkers. The loop forming thus requires some tension from the take-up rollers to hold the fabric down as the needles rise. The take-up has quite a different arrangement between flat and circular machines. On flat machines the angle of applied take-up tension to needle movement is equal for needles on each bed, while in the circular case it is approximately parallel to the cylinder needles and perpendicular to the dial needles. this necessitates a difference in technique for setting up and balancing between the two machine types.

It is quite easy to control the yarn feed at a constant rate as required on a circular machine but a balanced amount of yarn must be ensured for loops formed on each bed. For 1x1 rib it is quite easy to redistribute the yarn in finishing but this is an undesirable situation. It must be ensured that the same amount of yarn is drawn into the loops on each bed. This is rather complicated when the timing is not synchronised. By separating the drawing in to loops on each side of the fabric it is possible to get much greater control of yarn movement, but redistribution must take place within the structure on the knitting machine.

1.3.1.2 Limited Needle Selection

These fabrics can be produced on standard two bed machines either arranged with the needles on both beds opposite each other (interlock gating) or the needles alternating in position for each bed (rib gating). These machines generally have dual cam tracks on each bed and at each feeder selection takes place from the specific butt type of each needle.

1.3.1.2.1 Interlock and Interlock Based Fabrics

The simplest fabric produced with interlock gating is interlock fabric, where two 1x1 rib fabrics interlock with each other. This structure offers advantages in terms of stability over 1x1 rib fabric and is very important commercially^{37,38,51}. Because two separate structures are produced it is extremely important to ensure that the same amount of yarn is fed to both components. Here positive feed is imperative. This fabric is generally produced with a long delay (5 to 10 needles) between knitting on cylinder and dial.

Based on interlock there is another important structure which is probably the most stable of weft knits. This is known as punto-di-roma. Here plain courses on each bed are combined with interlock courses to obtain stability in extension in both the course and wale directions. The ratio between the lengths in the plain and interlock courses can be altered and hence the physical properties and the dimensions of the structure controlled^{12,30,38,39,41,42,46,131-133}. This ratio is referred to as the run-in ratio.

1.3.1.2.2 Rib and Rib Based Fabrics

In the same manner as 1x1 rib is developed by knitting alternate loops on alternate beds, a whole group of fabrics may be produced in which loops are formed and joined in groups from each bed. These fabrics, such as 2x2 and 2x1 ribs, are extremely extensible and are generally used as cuffs and bands to utilise this property⁵⁰. As general garment fabrics these are not very important.

Modified rib structures are, however, very important. Here, as in punto-di-roma, plain courses are introduced between the ribs to stabilise the structure. Perhaps the two most important of these fabrics are the Swiss and French double piqué fabrics. Half gauge plain is introduced alternately with 2x1 rib for both of these structures, the order of the dial needle choice determining which of the structures is produced. These fabrics offer good stability and are commonly produced on 18 gauge as women's outerwear or printing base fabrics. The structure requires two different feed rates; one to each section of the fabric. Half gauge plain presents some feed problems for a constant speed positive feed system, as only every second needle forms a loop, resulting in a wide variation in yarn requirements within the structure through the knit and miss repeat. The constant speed feed can only be set to feed at the average rate and so tension fluctuations will be large on the yarn as it enters the knitting zone. Constant speed feed gradually performs less successfully in knitting as more variation is presented within the basic repeat. As with the modified interlock structures, fabric properties can be altered by either varying the total yarn within the

cellular repeat or by varying the ratio of yarn between the components in the structure^{19,30,38,39,42,45,133,134}. The information from dimensional studies¹³⁴ has been presented in a computerised form to allow choice of fabric properties¹³⁵.

1.3.1.3 Jacquard - Full Needle Selection

These are the type of fabrics in which patterns are developed using different coloured yarns, generally the yarn is run at the back of the fabric and then drawn to the surface when that colour is required in the pattern. On single bed machines the yarn floats on the back of the fabric when it is not required for the pattern, whereas on two bed machines it is knitted onto the back set of needles when not desired. Having floats of yarn on the back of the structure is generally undesirable so the most important of these fabrics are the rib based two bed structures.

This work is primarily concerned with fabrics in which all loops should appear to be the same size on the surface of the structure. Thus only this group of jacquard fabrics are to be considered here. For such fabrics produced on two needle beds as modified rib structures, several methods of layout are used. These relate to the manner in which the yarn is held when not required on the surface of the fabric. This is usually as horizontal stripes, vertical stripes or by a "bird's eye" arrangement.

On horizontal stripe backed fabrics the yarn is knitted onto all the back needles when not required on the surface. Here there is a difference in the number of loops on the surface and back of the fabric. Usually only two colours

are used because of this imbalance. This arrangement has the advantage that no needle selection is required on the back needle set. This technique is popular for articles such as socks where there are space limitations on the machinery. Any variation between yarns or feed points will show as a structural barré across the fabric.

To balance the number of loops between the two sides of the fabric for two colours every second needle only is required on the back of the fabric. If these are laid out alternately (odd then even at successive feeders) and the colours also alternate the result on the back of the fabric is vertical stripes down the wale lines. This is undesirable as any variation between the yarns will result in vertical faults.

To break up the above effect either the knitting sequence of the needles or the order of the yarn layout must be altered. As the yarn is changed more often than the backing fabric layout, it is common to alternate the colours but arrange the back needles to knit odd-even, even-odd at four successive feeders with two pairs of colours. On the back of the fabric on each horizontal row or vertical row loops of each colour will alternate. This is referred to as bird's eye backing. It has the desirable feature of mixing the yarns of different colours so defects caused by any variation between yarns are minimised.

When fabrics with more than two colours are made it is general to keep this alternative knit miss of the backing needles. With three colours the selection of odd or even backing needles need just to alternate with feeders, and the colours taken in regular order, to achieve the bird's

eye back. Over three feeds (the colour repeat) one of the two back needles will knit twice while each needle on the surface knits once. Thus the ratio of loops on the back of the fabric to the front is 3:2 and consequently the loop geometry will be different from the unrestricted fabrics usually considered. To produce equal sized loops, three way selection would have to be possible on the back needle bed. A yarn not required on the surface of the fabric would have to float over two back needles between knitting needles. This would require a much more complicated machine and would produce a less stable fabric. The knit-miss backing requiring only two cam tracks, is used on the back of fabrics with up to six colours.

In the production of patterned fabrics a big difference appears between fabrics knitted on circular and flat machines. On the circular machine the colours must usually be laid out so that all colours are present in the fabric structure. With the flat bed machines though, the feeds and hence the colours are selected in pairs from the side of the machine. This of course allows for the production of technically two or three colour fabrics using changes in the base colours to introduce greater variation. Striping can be introduced at each feeder on a circular machine which would allow a similar technique to be used.

The properties of jacquard fabrics are dependent on the pattern. Some rather unsuccessful attempts have been made to consider jacquards in a like manner to that used for double knit fabrics^{136,137}.

For any of these fabrics the yarn requirements at any time are determined by whether or not the yarn is required

on the surface of the fabric. In this situation the existing positive feed techniques cannot be used at all. If a patterning restriction is introduced in which, over a certain section of the fabric the same length must be used at one feeder this can perhaps be fed at constant speed. This would however be rather complicated to implement and the freehand designing offered by full needle selection would be lost. Thus the best feed available is a constant tension type using a storage feed mechanism.

1.3.2 Rib Jacquard Yarn Requirements

Much work has been concentrated on examining the common double knit structures (which do not require full needle selection) relating loop length (or length of yarn in the cellular repeat), run-in ratio and cover (or tightness) factor to fabric properties. This basic information should be useful in helping to understand jacquard structures. However, for full needle selection the studies have concentrated on attempting to predict yarn consumption for a given pattern. For a factory producing patterned fabric this is of course critical for regulating yarn stocks.

For the common two colour rib based jacquard structures the yarn consumption has been examined by first breaking the structure into units of loops and joins between these loops¹³⁸. Five different units are found within the structure. As it is very difficult to separate out these units for measurement purposes, this system proved unsuccessful. A further system took the machine geometry as its starting point and used as its repeat the length between three knitting needles^{139,140}. With this approach

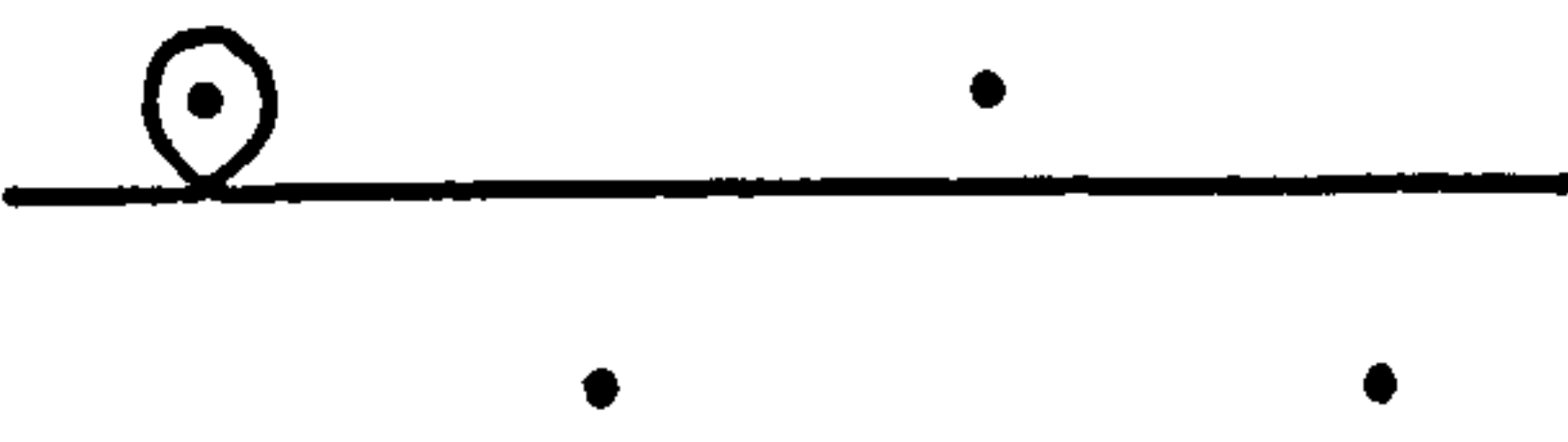
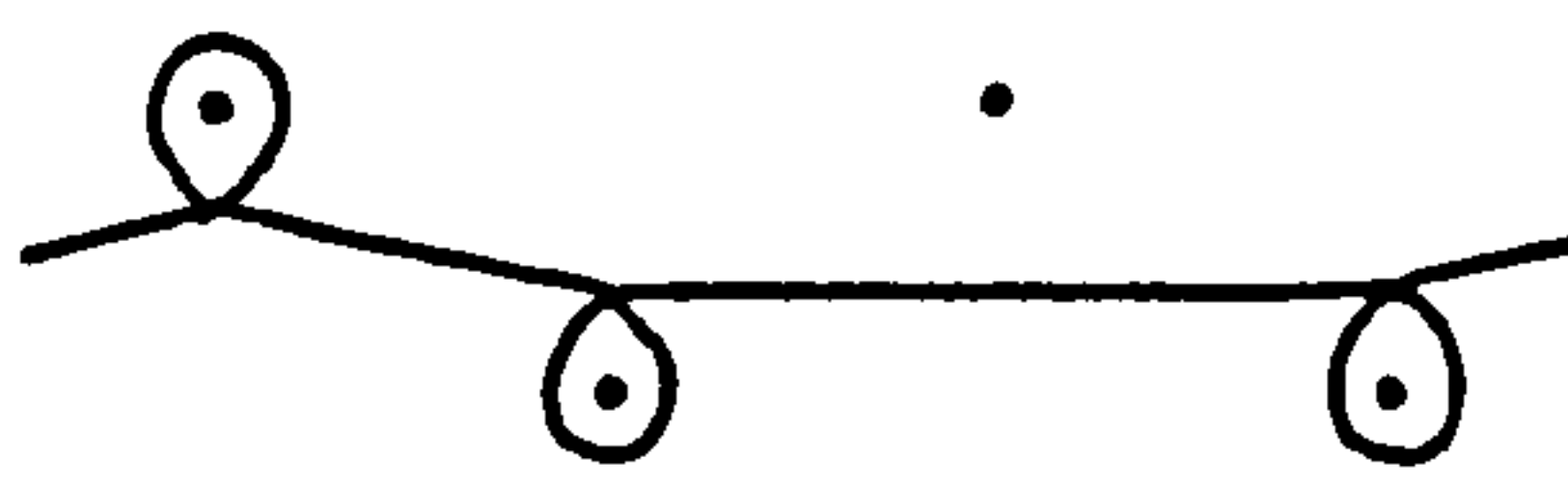
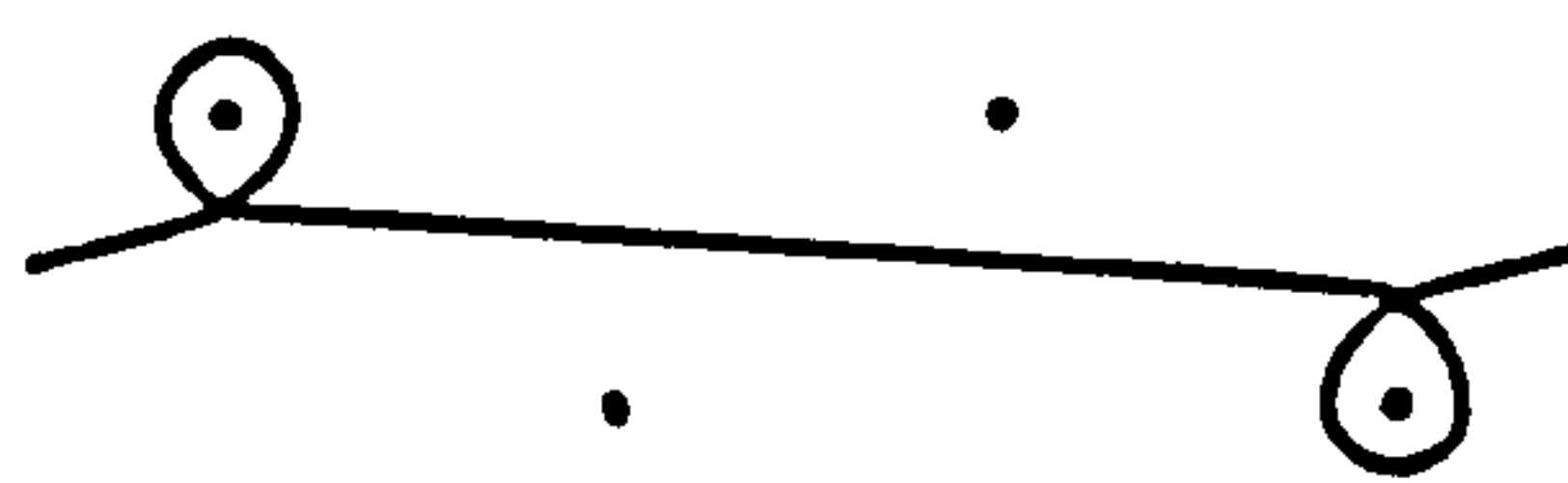
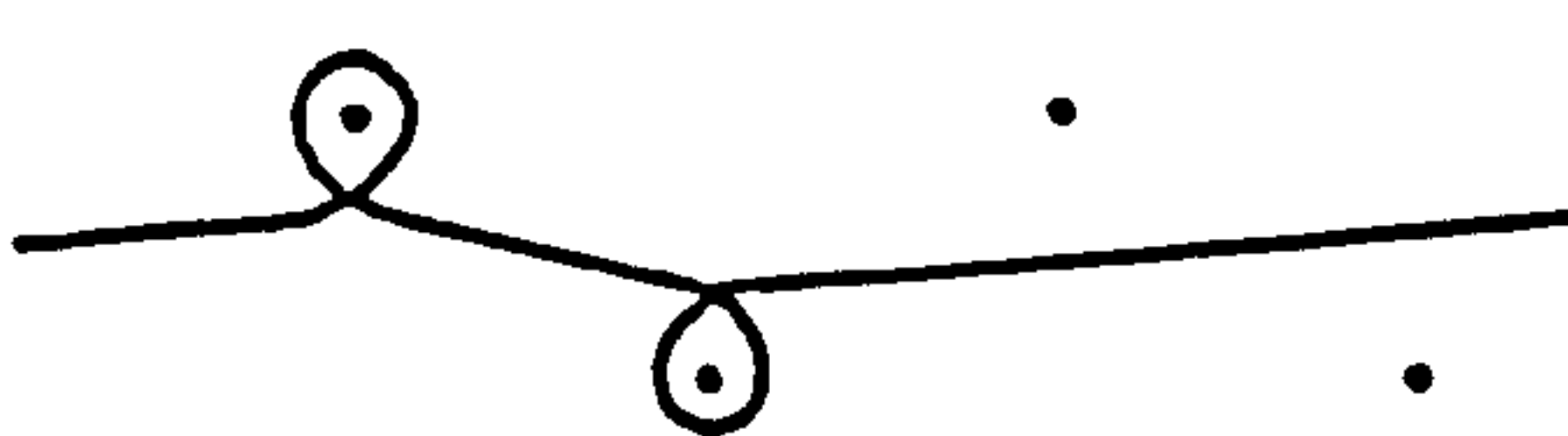
<u>Loop configuration</u>	<u>Unit</u>	<u>Length</u>
	1000	L_{1000}
	1101	L_{1101}
	1001	L_{1001}
	1100	L_{1100}

Figure 1.5 Basic jacquard units with nomenclature.

seven separate units were found. Again determining the exact length of these units poses a problem. Here the lengths were derived from measuring course lengths of all miss, all knit and knit miss combinations of needle layout.

Using these two studies and a third model based on the second of these previous studies Fahmy and Newton go to great lengths to prove mathematically that all the elements necessary to make up the fabrics can be spanned by three units¹⁴¹⁻¹⁴⁴. However, for all their trouble to prove this, it is an extremely simple observation. The basic repeat in the fabric is between two knitting dial needles. Between these either no, one or two cylinder needles will knit, as shown in Figure 1.5. The entire fabric can then be broken down into a combination of these three units. The units can be independently measured when setting up the machine as shown by Kidacki¹³⁹. This concept of independent units within the jacquard structure is most important in developing any understanding of the properties of jacquard fabrics.

In Figure 1.5 a loop specification is shown designating each needle in the order it passes the feeder with a 1 if it knits and a 0 if it misses. The first needle is on the dial or back of the fabric. Thus the all miss becomes 1000, the all knit 1101 and the knit miss either 1100 or 1001 depending on which needle knits first.

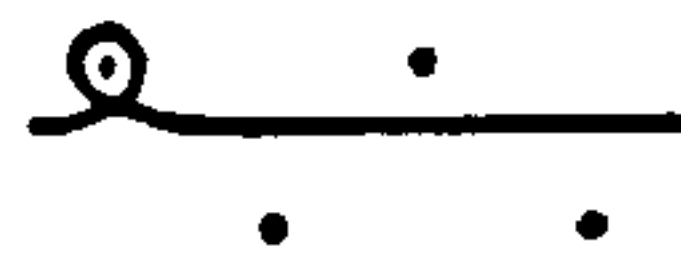
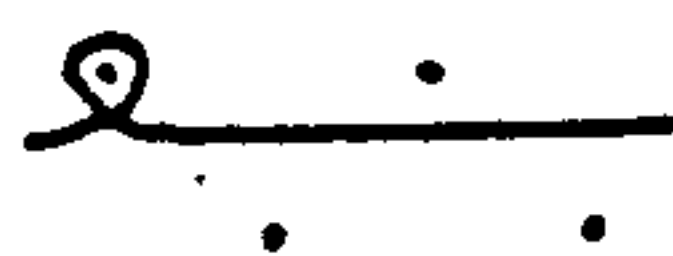
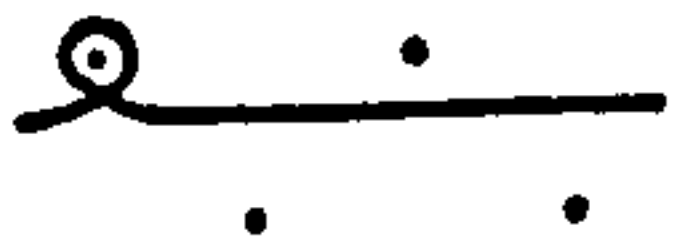
A two colour flat jacquard with bird's eye back requires the colours to be set out in pairs. Needles either knit one colour or the other in a two feed repeat. This means that only two cellular length arrangements of the three base length groups are present. These are when both cylinder needles knit the same colour with the other colour knitting



$$L_{1000} + L_{1101}$$

$$2L_{1001}$$

Figure 1.6 Two colour length combinations.



$$2L_{1000} + L_{1101}$$

$$2L_{1001} + L_{1000}$$

Figure 1.7 Three colour length combinations.

on the dial only, and when only one cylinder needle is used with each colour. The total length in the cell is then either $L_{1000} + L_{1101}$ or $2L_{1001}$, where L_{1000} , L_{1101} and L_{1001} are lengths as shown in Figure 1.5. To produce a fabric of consistent tightness these cell lengths must be equal. Hence $L_{1000} + L_{1101}$ must equal $2L_{1001}$. This means that the loop combinations shown in Figure 1.6 must be equal.

The yarn usage, if $L_{1000} + L_{1101} = 2L_{1100}$, will be proportional to the number of surface loops. If the length required for any two units is known, and the relationship holds, the total yarn length can easily be calculated. The Digitex computerised pattern preparation system¹⁴⁵ uses this arrangement to predict the percent usage of each colour within the pattern. It requires the length for an all knit and the length for an all miss unit to be fed in as data in order to perform the calculation. However this program gives no consideration to the possibility that the length groups may not be equal.

The above approach can be extended to three colour jacquard patterns with bird's eye backing. Figure 1.7 shows the length combinations within the three colour fabric. Here, as in the two colour case, the units can appear in any order for the cylinder with the dial layout fixed. The total length of the groups becomes:

$$2L_{1000} + L_{1101} = 2L_{1100} + L_{1000}$$

$$\text{or } L_{1000} + L_{1101} = 2L_{1100} \quad \text{as found for the}$$

two colour case. For any sequence of knitting which has a knit miss backing, this relationship will hold true.

To produce cells of consistent weight the relationship becomes dependent upon the dimensions of the base cells. In

colour



FDP
colour 2 on surface

SDP
colour 1 on surface



2x1 rib interlocking with $\frac{1}{2}$ gauge plain

Figure 1.8 Combinations of 1101 and 1000 units in structural cells of two colour jacquards.

the case of the two colour arrangement with bird's eye backing, the backing repeat is over four feeds and it is this which should be examined for structural considerations. For the units in which two needles knit between each dial needle, four structural combinations exist. These are: all one colour, all the other colour, stripes with one colour first and stripes with the other colour first. These are shown in Figure 1.8. The first two cases are the familiar Swiss double piqué (SDP) and French double piqué (FDP) fabrics. Comparative results³⁸ for parameters of these fabrics in the fully relaxed state are shown in Table 1.3. The parameters used are defined thus:

$$U_c = C_u \times L_u$$

$$U_w = W_u \times L_u$$

$$U_s = U_c \times U_w$$

$$U_c / U_w = C_u / W_c$$

where L_u = total length of yarn in structural knitted cell

C_u = course units per unit fabric length

W_u = wale units per unit fabric width

This uses the concept of the structural knitted cell. The fabrics were knitted with the same run-in ratio of 2.2:1.

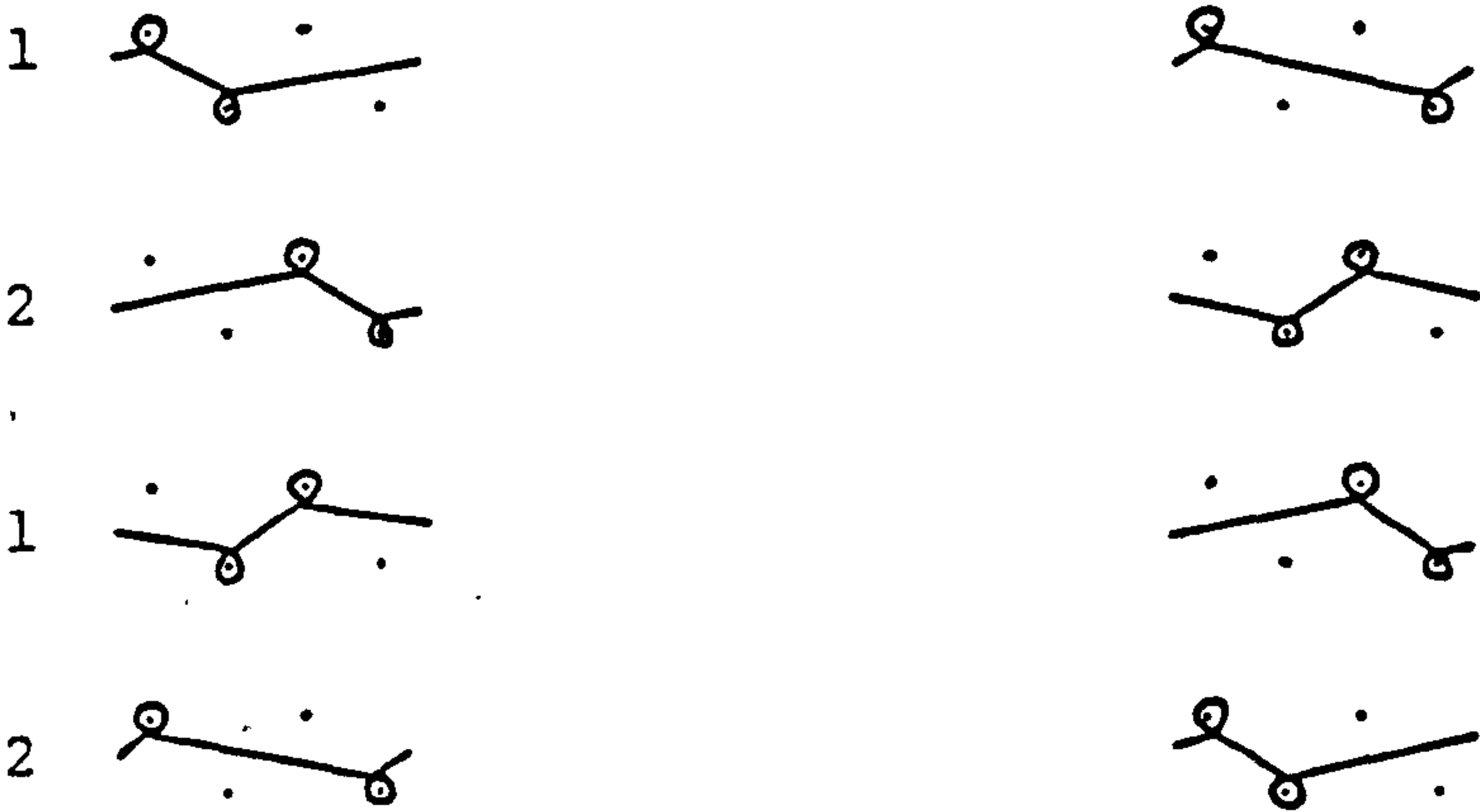
It can clearly be seen that SDP and FDP will vary in their dimensions. FDP produces a wider and shorter base unit than SDP. It has been found¹⁴⁶ that FDP can be produced with run-in ratios from 1.5:1 to 2.7:1, while SDP can be produced in the wider range of 1.2:1 to 2.7:1. Optimal run-in ratios in terms of dimensions are 2.1:1 for SDP and 2.3:1 for FDP¹⁹. Here FDP is found to be more sensitive to changes in run-in ratio than SDP.

In the practical situation, however, it is difficult

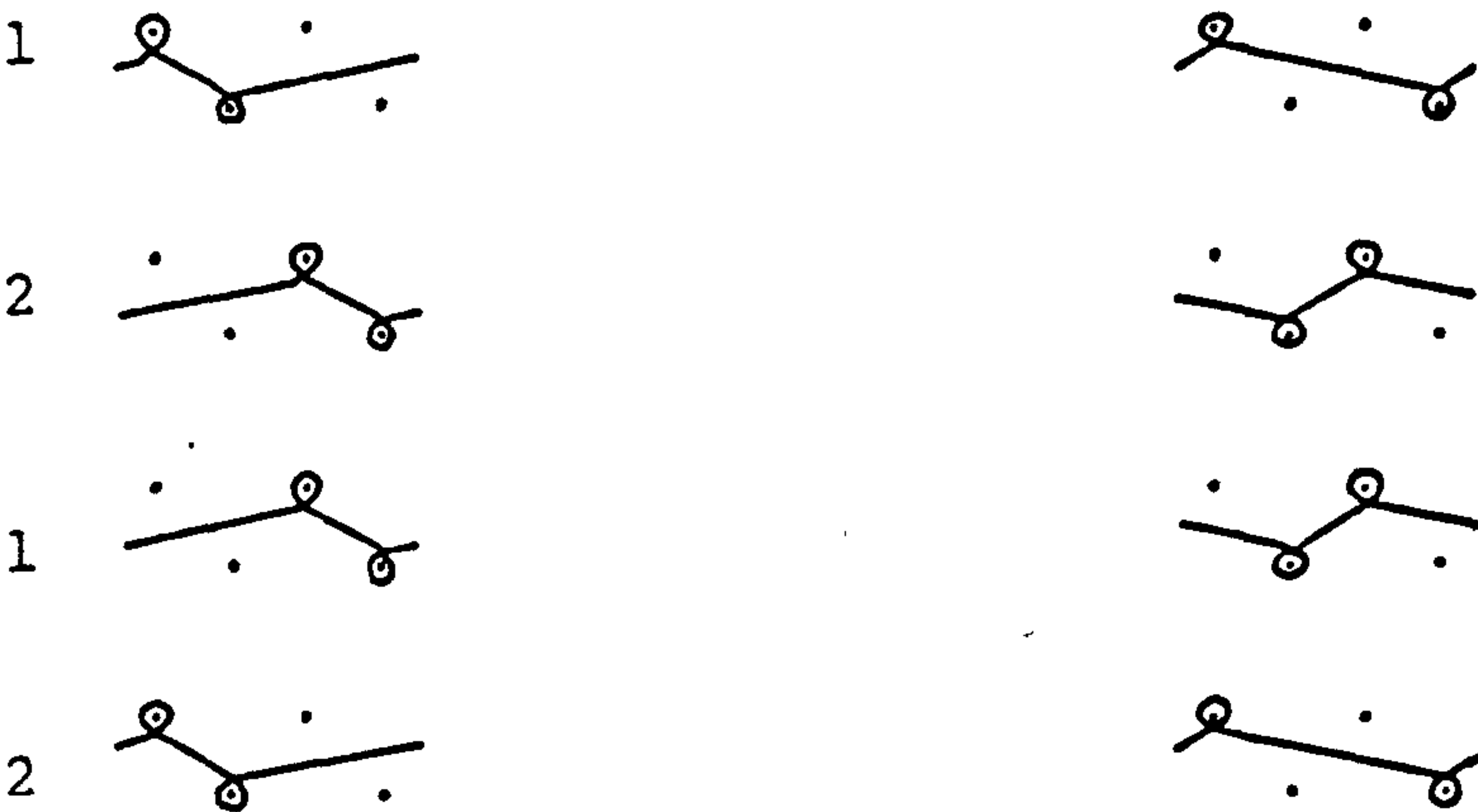
Table 1.3

Results for parameters of various fabrics in the fully relaxed state.

Fabric Type	U_s	U_c	U_w	U_c/U_w	Optimum Run-in
Interlock	382	21.2	18.0	1.18	1:1
SDP	379	21.3	17.8	1.20	2.1:1
FDP	386	25.9	16.6	1.56	2.3:1
2x1 rib, ½gge plain	352	20.6	17.1	1.24	2.0:1



Interlock type (vertical stripes)



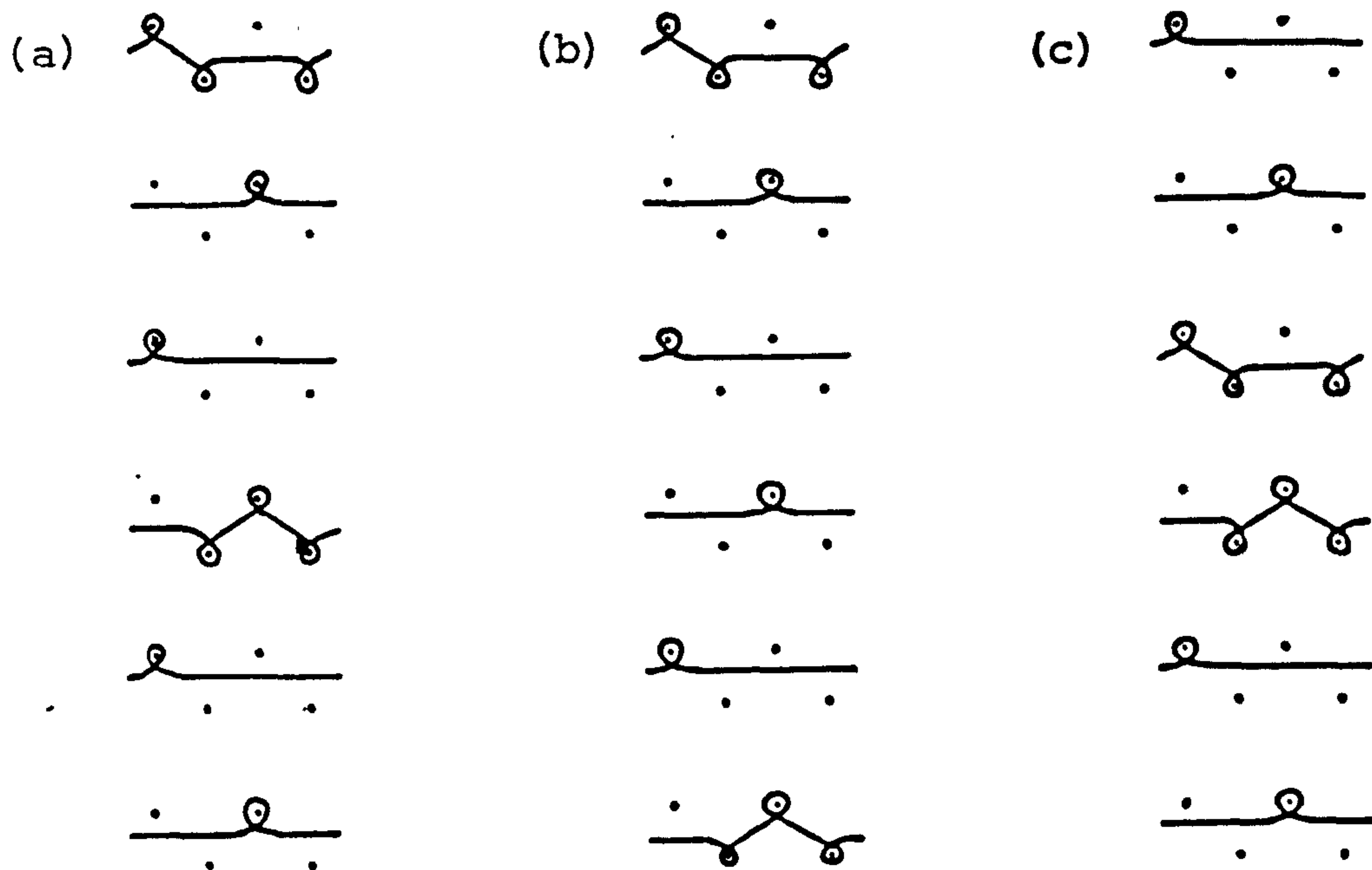
Modified interlock ("bird's eye front")

Figure 1.9 Combinations of 1100 and 1001 units in structural cells of two colour jacquards.

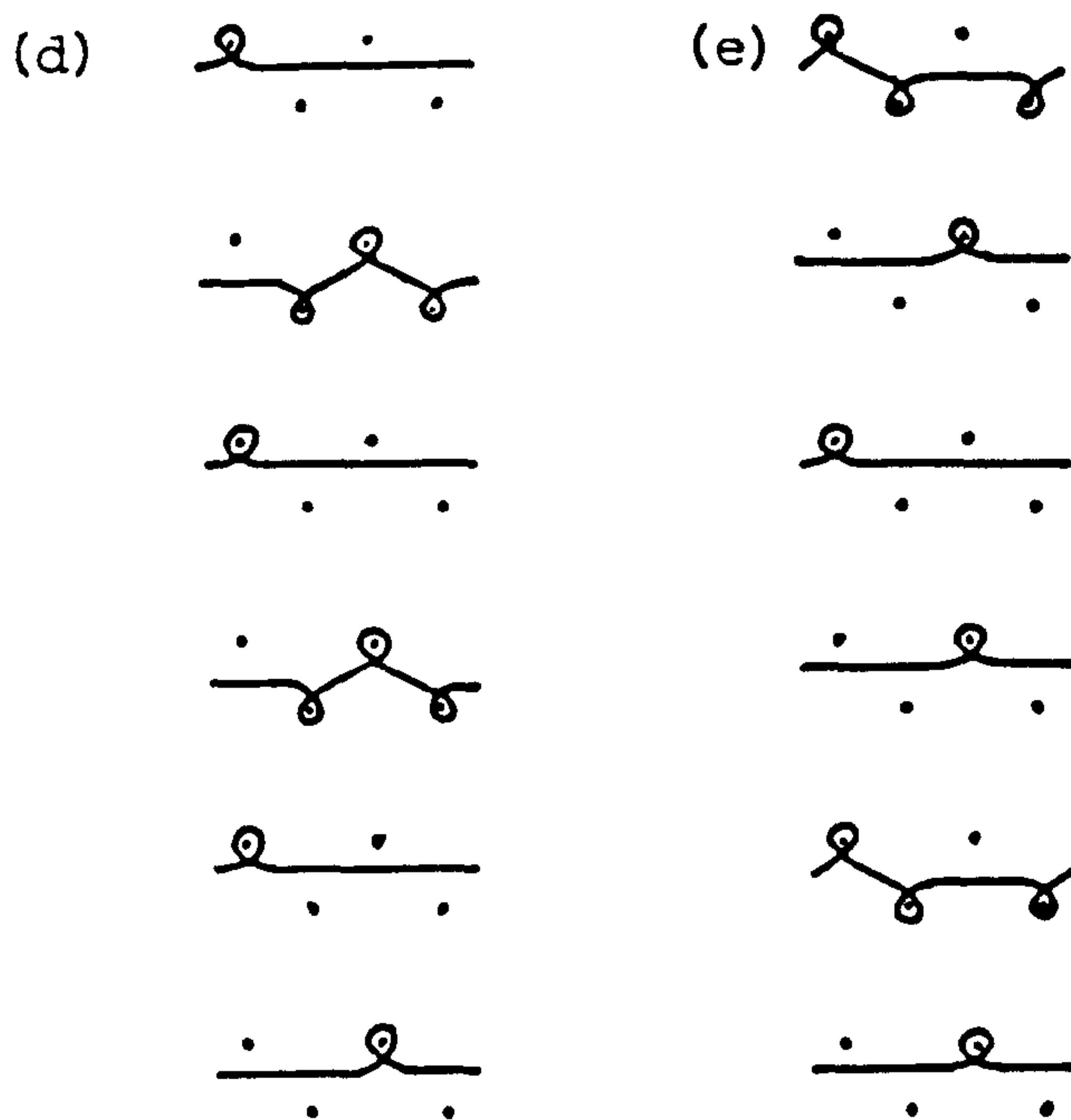
to apply this information to the jacquard structure as a whole. Large unmixed areas of the colours will act as SDP or FDP respectively. With negative feed the amount of yarn taken into each unit could vary and "balance" the structure but it is likely that the fabric would either look different or feel different for the two units.

If the second two arrangements are also considered further complication arises. Here the fabric is formed as a 2x1 rib interlocking with a half gauge plain. These units should be much more alike dimensionally than the FDP and SDP units but would likely be unstable. Values of the dimensional parameters of this unit are also shown on Table 1.3 for fabric again at the 2.2:1 run-in ratio¹⁴⁷. Here the values lie close to the SDP but with a slightly lower U_c and U_w . This fabric was produced using acrylic, and not wool as for the previous results, and was not vigorously relaxed. The appearance of this particular fabric is like that of 2x1 rib with marked lines along the fabric. A much smaller range of ratios of only 1.7:1 to 2.2:1 was found to be possible in production. An optimum ratio for this fabric based on the same consideration as for SDP and FDP gives 2.0:1.

Where one cylinder needle is knitted between each knitting dial needle, two basic cases result, as shown in Figure 1.9. These are either interlock or a stabilised form where the interlock moves between successive needle pairs on successive courses. The dimensional properties of fully relaxed interlock³⁸ are shown in Table 1.3 for a run-in ratio of 1:1. Here the resultant fabric from the same input length is slightly narrower than for SDP but of a similar



double piqué type combinations



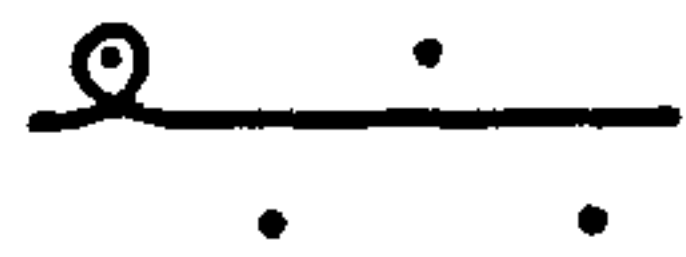
rib type combinations

Figure 1.10 Examples of the 1101 combinations for three colour jacquard.

length. It is doubtful that the interlock knitted with rib gating will be able to reach full relaxation with the loops opposite each other. The stabilised interlock would be expected to be much closer to the SDP, as the fabric would be constrained in the width direction.

It would seem that the interlock type units should be produced with the same amount of yarn as the SDP units to achieve the same dimensions. The greatest variation comes between the SDP and FDP corresponding to unmixed areas of the two different colours. The 2x1 rib interlocking with half gauge plain and the interlock produced on rib gating however, would be extremely unstable units within the fabric.

For three colour fabrics produced with bird's eye backing a six feeder repeat must be chosen for a structural repeat with the same colour starting at the same point relative to the same backing needle. The arrangements with two cylinder needles knitting between knitting dial needles are shown in Figure 1.10. Unfortunately dimensional data is not available for these structures as none of them are commercially produced in a repeated form but only as part of a patterned fabric. The combinations however are of two types : those in which both units appear between the same pair of dial needles and those in which they appear between the opposite set of dial needles. Both of these are separated by a set of dial only units except in the case shown in Figure 1.10(c). The interlock style arrangement of 2x1 rib and half gauge plain, which exists when the cylinder needles knit between the same pair of dial needles, will be structurally unsound as found in the two colour case. Overall it would be expected that these would be dimensionally



interlock type



modified interlock type

Figure 1.11 Examples of the two types of 1100 and 1001 combinations for three colour jacquard.

Table 1.4
Two Colour Jacquard Results

Source	Unit Name	Unit	Length	$\frac{2L_{1101}}{L_{1101}+L_{1000}}$	$\frac{L_{1101}}{L_{1000}}$
Kidacki & Dyson ¹³⁹	alternate needles plain	AxL_{1000}	(in/course) 131.1	1.16	2.47
	interlock	AxL_{1100}	267.2		
	all cylinder alt.dial	AxL_{1101}	324.4		
Fahmy & Newton ¹⁴⁴	B_2	L_{1000}	(cm) 0.4323	1.11	2.28
	B_3	L_{1100}	0.7428		
	B_1	L_{1101}	0.9828		
Fahmy & Newton ¹³⁷	B_2	L_{1000}	0.394	1.14	2.62
	B_3	L_{1100}	0.816		
	B_1	L_{1101}	1.034		
	B_2	L_{1000}	0.463	1.14	2.95
	B_3	L_{1100}	1.045		
	B_1	L_{1101}	1.367		

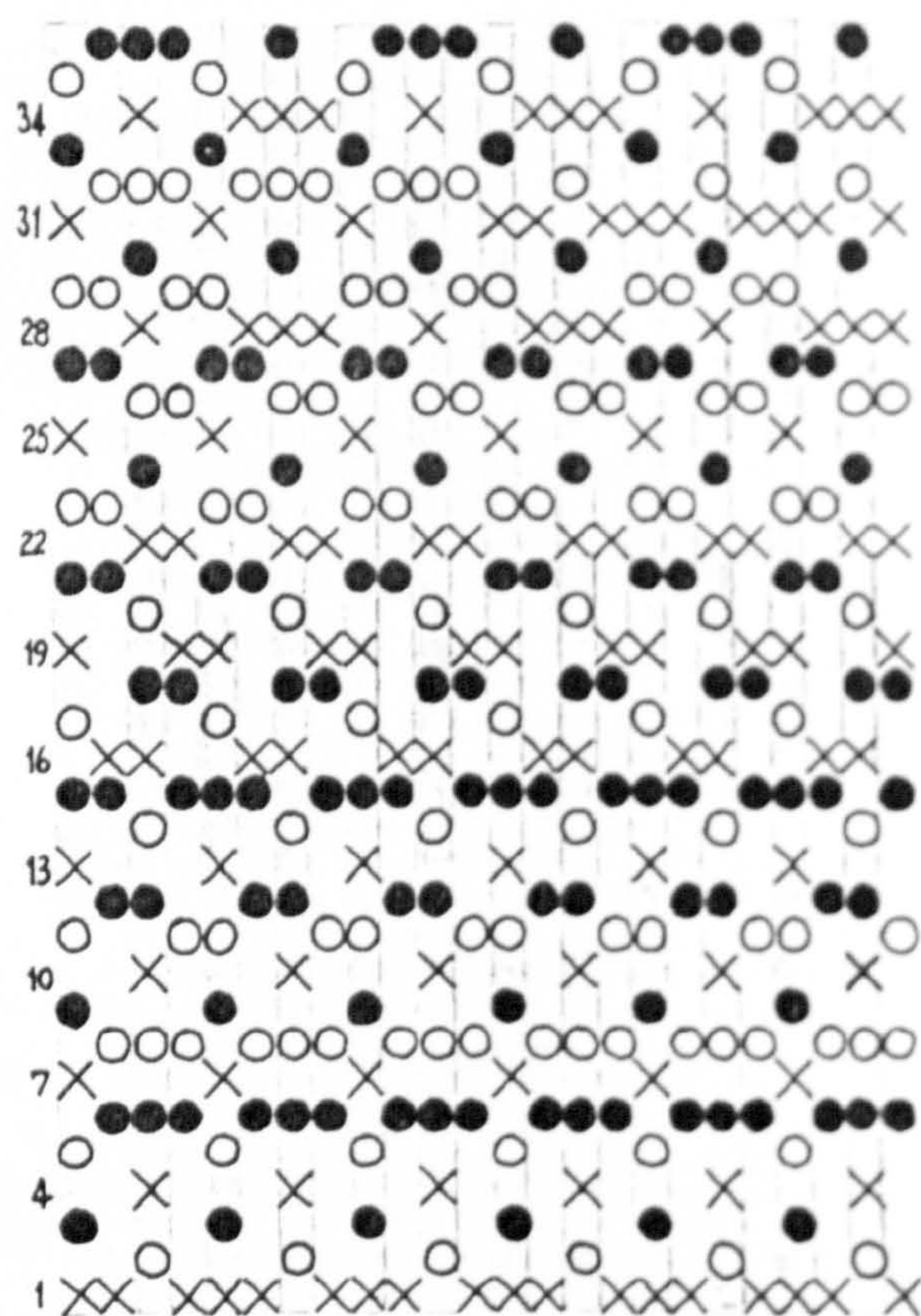
closer than in the two colour case due to the presence of the dial only units.

The single needle units also appear in two forms : interlock separated by dial only feeds and stabilised interlock as can be seen in Figure 1.11. These represent one stable unit and one unstable unit as found in the two colour case.

1.3.3 Knitting Jacquard Fabric

During their discussion of yarn length theories both Kidacki and Dyson¹³⁹, and Fahmy and Newton¹⁴⁴ present an example of experimental results for two colour jacquard. These are shown in Table 1.4. The units are given as taken from the respective papers : Kidacki and Dyson measuring the course length and quoting it for the three units, while Fahmy and Newton quote their lengths as cell lengths. The ratio $2L_{1100} : (L_{1000} + L_{1101})$ gives a measure of how equal the interlock and piqué units are. The value of this ratio is 1.16 and 1.11 respectively. Thus the density of the fabric would be different where the different units appear within the structure, the interlock units being produced more than 10% more open than the double piqué units.

The ratio $L_{1101} : L_{1000}$ can be compared to the run-in ratio for the double piqué fabrics¹⁴⁶. This ratio is 2.47 for Kidacki and Dyson's fabric and 2.28 for that of Fahmy and Newton. It is not known whether the units are of the Swiss or French double piqué type. Nevertheless, considering that 2.3 represents the optimum for FDP and 2.1 for the SDP ratio, it would seem likely that the former fabric was structurally unsound. Fahmy and Newton¹³⁷ knitted a further



X colour 1 ● colour 3
 O colour 2 ↓ dial needle

Figure 1.12 Pattern of the experimental jacquard fabric.

Table 1.5

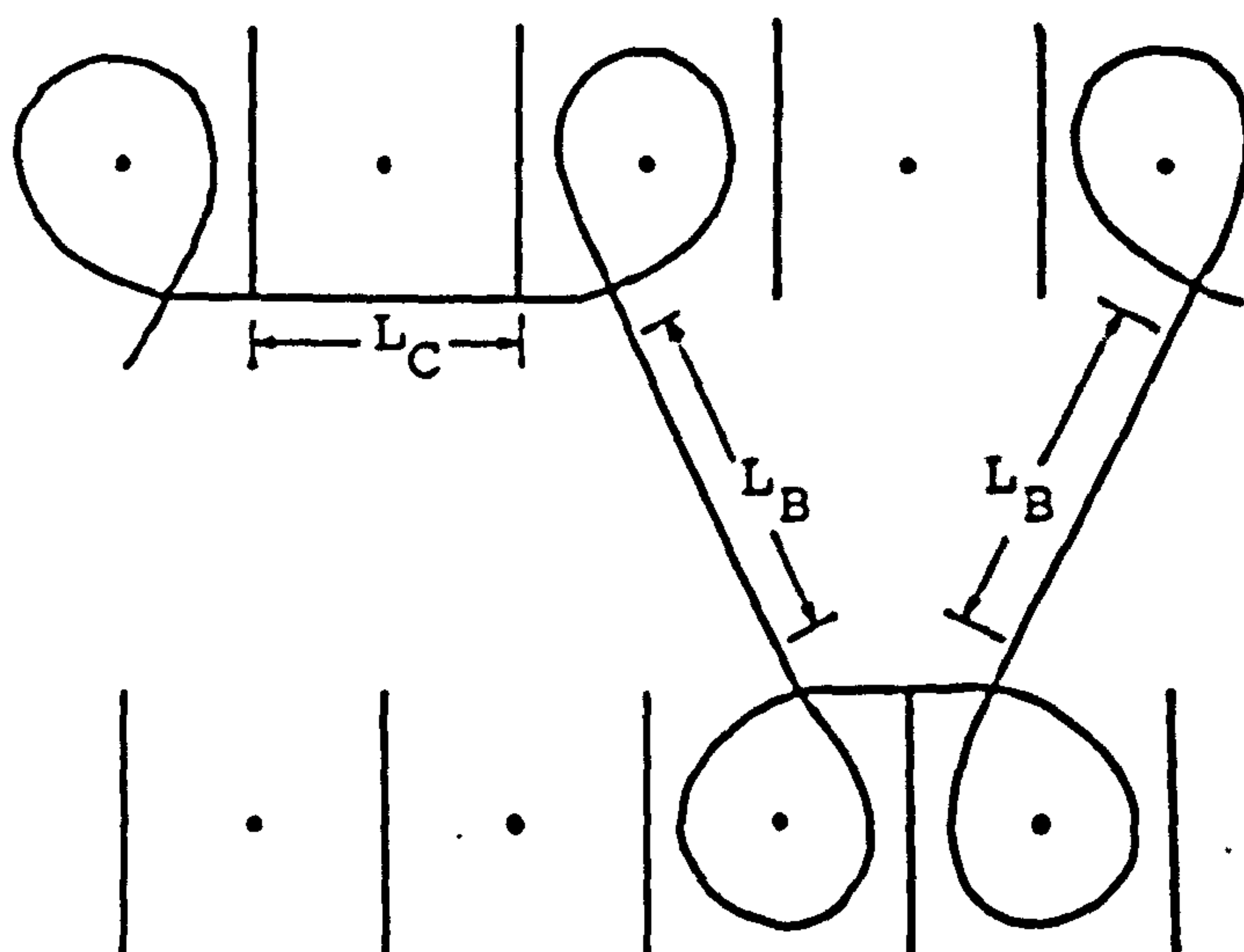
Mean values of cell lengths in millimeters.

Fabric	L_{1000}	L_{1100}	L_{1101}	$\frac{2L_{1100}}{L_{1000}+L_{1101}}$	$\frac{L_{1101}}{L_{1000}}$
1	5.07	9.71	11.87	1.15	2.35
2	5.06	9.95	12.88	1.11	2.55
3	5.00	10.53	13.47	1.13	2.69
4	5.04	10.97	14.36	1.13	2.85

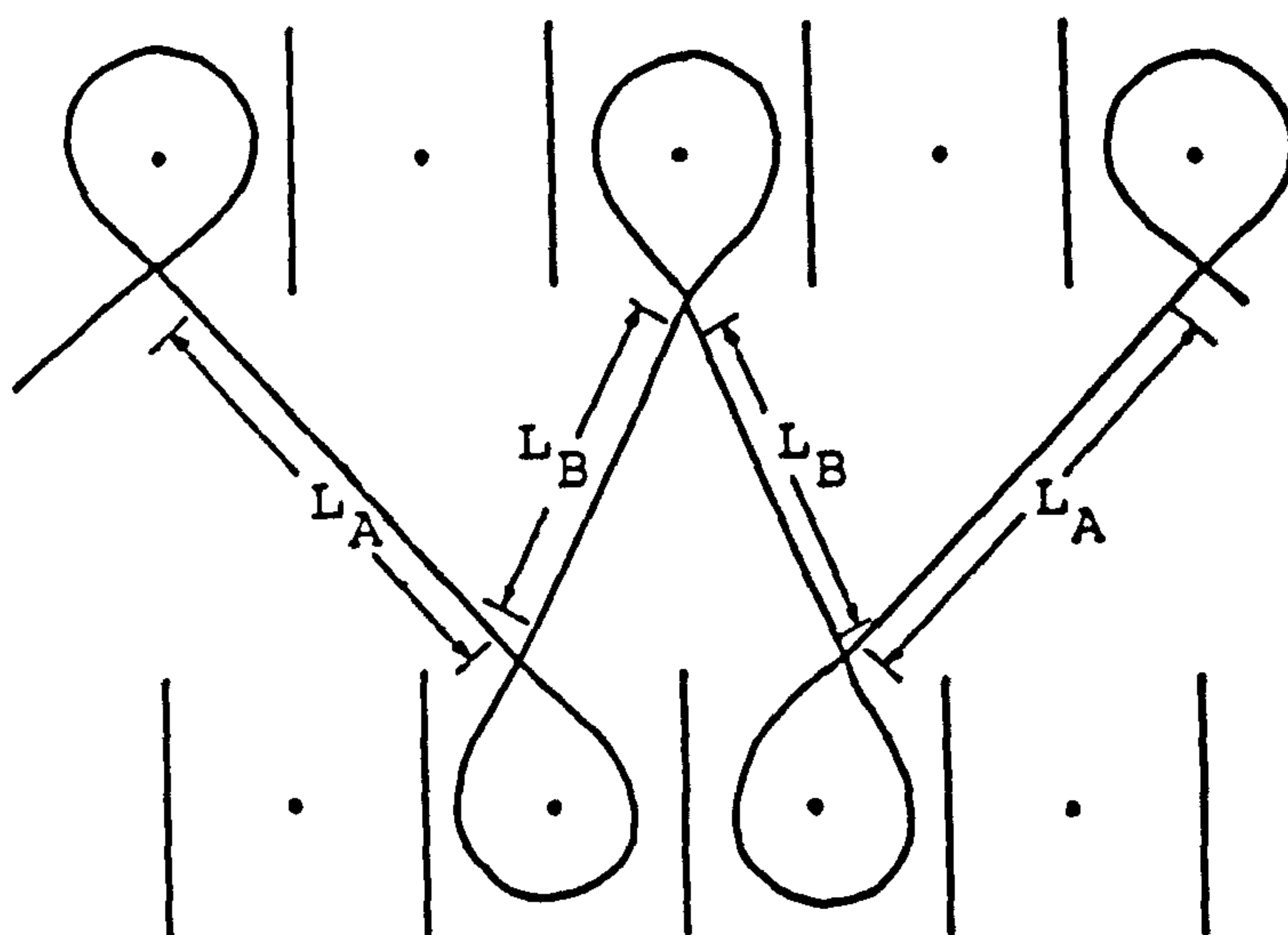
range of fabrics to examine the effect of various knitting parameters on two colour jacquard. The two samples shown in Table 1.4 represent the highest and lowest values of $L_{1101} : L_{1000}$. This ratio range of 2.62 to 2.95 is much higher than those produced previously and much higher than the 2.2 value suggested by Knapton for double piqué fabric³⁹. Here the interlock combination again gives over 10% more yarn than the double piqué unit.

To examine the possibilities of this effect within the jacquard fabrics, including three colour jacquard, a series of fabrics were produced. These fabrics were all the same pattern with each feed being a repeat of one of the length groups. The pattern is shown in figure 1.12. Here a slightly unusual layout of the design is used to enable examination of the relationships between surface and back loops. The selection of all needles both dial and cylinder, is shown with the arrangement being sequential over where the needle passes the feed point. A range of fabrics was produced with different cam settings and a technique of feed mixing was used to remove any feed point effects. All values of the length groups and a description of the production method are given in Appendix 4.

The mean values of the lengths L_{1000} , L_{1100} , L_{1001} and L_{1101} are shown in Table 1.5. Although a three colour basic fabric is produced here, the ratio $2L_{1100} : (L_{1101} + L_{1000})$ is approximately 1.13, as found in the two colour case, under all conditions. Thus the interlock will again represent a more open section in the fabric. The ratio $L_{1101} : L_{1000}$ gradually increases from 2.34 to 2.85 which again is similar to the two colour results. However, because



$$\text{Total length} = 5 \text{ loops} + L_C + 2L_B$$



$$\text{Total length} = 5 \text{ loops} + 2L_A + 2L_B$$

Figure 1.13 Length combinations for structural units 1000+1101 and 1001+1100. Here an extra loop is shown on each combination for clarity.

of the imbalance of the loop sizes due to the three colour layout, it would be expected that a higher ratio is required than in the two colour case. Here a ratio of approximately 2.6 would be expected to give the same dimensional optimum as given by 2.2 for two colours¹⁴⁷.

A problem arises, however, primarily in the production of long interlock combinations. Consider again the loop formation of the two structural units on the knitting machine with reference to Figure 1.13. If the loops are of the same size the crosslinks will give the difference between the units. These will be $2L_B + L_C$ for the first combination and $2L_B + 2L_A$ for the second. Here then L_C must equal $2L_A$ for the total lengths to be the same. The separation of loops on the machine will give L_C as approximately $1/(\text{machine gauge})$ so consequently L_A must equal $1/(2 \times \text{gauge})$. This is the distance between the edge of the trick on the dial and the edge of the projection of the cylinder trick onto the dial. That is, there is no length allowance for crossing between one needle bed and the other. The result is that $2L_{1100} > L_{1101} + L_{1000}$. This result is similar to that found between rib and plain where a 17% greater length in rib for the same loop size has been reported¹⁴⁶.

To achieve the desired result a means of either reducing L_{1100} or increasing $L_{1000} + L_{1101}$ must be found. Because there is nothing to hold the joins between the loops formed on the same bed, these will always lie along the verge. Hence it is not possible to move the formation point to the centre line between the needle beds. In a jacquard fabric all three units must be able to be formed at a single feed

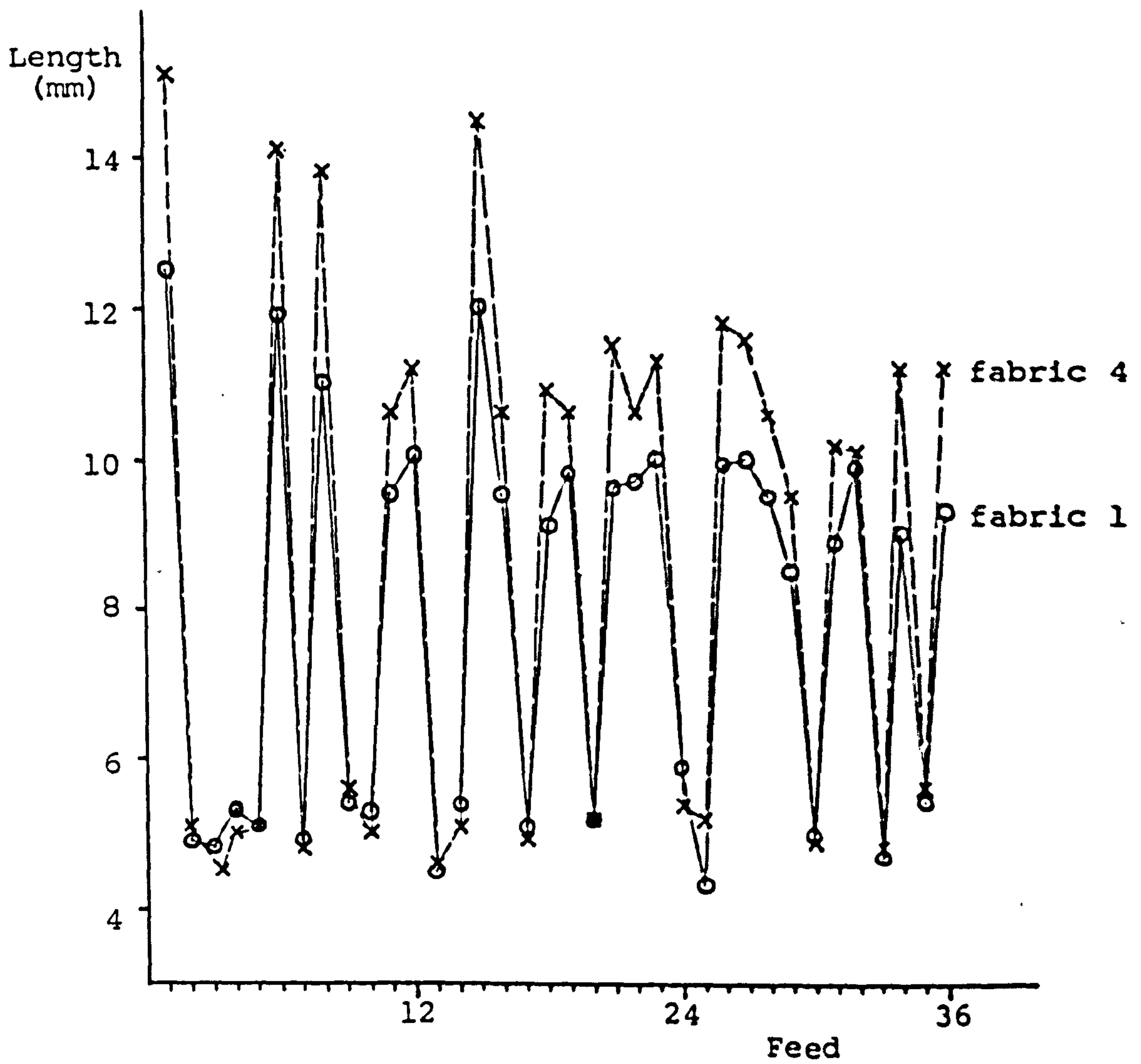


Figure 1.14 Length of units for individual feeds in fabrics 1 and 4.

so tension or cam setting cannot be used to control the lengths between the various units. When producing the fabric in the negative feed case, directly off a cone, the 1101 unit will require the highest speed and hence develop the highest tension and so will be reduced in length relative to the slower 1000 and 1100 units. This will move the balance even further towards the 1100 units. The best possible arrangement will be produced with the largest loops and the smallest separation between the needle beds. However, if the loop size is increased, so is the fabric thickness, requiring a greater space between the needle beds. The only possible way of gaining the desired relationship between L_{1000} , L_{1100} and L_{1101} would be by positive feeding of the yarn. This would still require higher tensions to be produced on 1100 units to reduce their relative size as the cams at each feeder still must be set the same.

As discussed previously the jacquard fabric consists of a combination of units. Some of these units are stable and some are unstable. Also the units when found in isolation are not producible over the same ranges^{146,147}. In the negative feed case the knitting will be affected by the structural stability of the previous cell and also by the time the previous loop has been held on the particular needle. The effect here will be a localised change in the take-up tension and hence a change in loop length drawn. This can be examined on the fabrics previously produced. Figure 1.14 shows a graph of the various lengths produced at various feeds in the pattern.

If the pattern is broken down in order to examine its

Table 1.6

Comparison of various units within three colour jacquard fabric samples.

Unit	Fabric			
	1	2	3	4
Mean L ₁₀₀₁	9.74	10.09	10.57	10.93
Mean L ₁₁₀₀	9.67	10.11	10.69	11.18
Feed 8	11.03	11.39	12.05	13.87
Mean L ₁₁₀₁	11.86	12.88	13.47	14.36
Feed 29	8.54	8.90	9.24	9.54
Mean L ₁₁₀₁ +L ₁₀₀₀	8.50	9.00	9.25	9.75
Interlock Mean	9.78	10.05	10.63	10.95
Modified Interlock Mean	9.60	9.79	10.37	11.02

structural cells it is found that feed 6 knits a double piqué style unit with feed 1, with several half gauge plain courses in between. Feed 8 follows, knitting a 2x1 rib with feed 6, again separated by a half gauge plain. By examining the 1101 units as shown in Table 1.6, it is seen that feeds 1, 6, and 15 are similar in length, with feed 8 shorter. It is this feed of course which is knitted in the structurally unsound arrangement previously found to knit shorter than the double piqué units¹⁴⁷. As yarn movement is free within the structure with this unit, an effective reduction in the take-up force can result in a reduction in L_{1101} . Feed 15 follows an interlock pairing of previous cylinder loops and is the next shortest of the 1101 units. Feed 6 has loops held for the longest possible time (since feed 1) but is not very different from the other 1101 groups.

Examining the 1100 and 1001 units, it is seen that feed 12 follows feed 11 in interlock combination as do feeds 22, 26, 27 and 29 respectively, while feeds 18, 19, 21 and 28 follow in the more structurally stable condition. Here the length difference is not as great but the loops on the surface of the fabric appear uneven. This is caused by the redistribution of neighbouring loops which have been held for varying times on adjacent needles. This seems especially bad in interlock combinations where skew in the wale lines is observed⁹⁴.

The sequential behaviour of needles at a single feeder can be examined. Feed 28 represents alternating 1100 and 1001 units as do feeds 34 and 36. These give results very close to either 1100 or 1001 repeating. Here it is found

that there is some variation between 1100 and 1001 units, especially where the cam settings on each bed are not the same (feeds 11, 12, 16, 19, 26 compared with feeds 18, 21, 22, 23, 27).

Feed 29 gives 1000, 1101 units repeated and lies in the range of the average of the two units as found individually. Feeds 31 and 32 also have 2 x 1000, 2 x 1100 and 2 x 1101 units in the repeat and give an increase in length over the feed 29 length but are less than the 1100 units alone. It seems the sequential knitting at the same feed has only a small effect on the length drawn.

It is important to note that the effect of the previous loop on the needle (and hence the take-up tension) is vital in determining the length drawn. Effects due to the previous needle moving along the cam however seem to be very small. Nevertheless both of these would be expected to affect yarn movement within the knitting zone.

Thus the conditions for producing consistently stable jacquard fabric seem to vary considerably. Without extreme restrictions on the designer many of these effects cannot be reduced. If the 1100 and 1001 units are not used in the structure, consistent density can be achieved along with a reasonable measure of stability. Even if only the paired needle unit 1101 is used, combinations of 2x1 rib will result in structural instability, while FDP and SDP units have different dimensional properties. Positive feed could cure the feed length difficulties but fabric stability would still be a problem.

Perhaps an important consideration here is the preparation of the machine for knitting jacquard fabric.

Kidacki^{139,140} set up the machine by first knitting plain fabric on each bed and setting the cams so that they were both drawing the same length of yarn. This would seem reasonable for flat bed machines but the circular machine will behave very differently knitting plain on the dial or the cylinder due to the different angles these beds present to the take-up tension application. Kidacki then measured the interlock and all knit units. A more commonly used method requires that all cams be set to the same depth¹⁴⁸. Here no measurement of the feed lengths is taken.

Perhaps the best, if a rather lengthy, technique requires each feed to be checked for feeding the L₁₀₀₀ and L₁₁₀₁ cells. Once these are set, the L₁₁₀₀ is also automatically set. The L₁₀₀₀ cell can be set using the dial cams and the L₁₁₀₁ cell using a combination of cylinder cams and dial height¹⁴⁹.

1.3.4 Knitting Data Presentation and Analysis

Because there are structural as well as the length associated problems in jacquard knitting it is desirable to be able to predict the type of structural units that will exist within a pattern as well as the best method of laying out the colours. This may offer the possibility of minor alterations to the pattern with some structural benefit.

Traditional patterning starts with the production of a squared paper design describing the appearance of the surface of the fabric only. Fabric designers are generally trained along traditional lines and this starting point is hence easiest and most comfortable for them. This method however is far from ideal since even colour change effects

are difficult to estimate without redrawing the design. Any analysis in terms of length or structure would be rather difficult. It is thus desirable to translate the design data into some form which can facilitate further analysis. A video monitor offers ease of colour change and, if driven from a microprocessor which stores the pattern, the data is available for analysis. Several methods exist for transferring the design to the screen^{150,151} : direct typing from a keyboard, digitising table, paper reader, graphics tablet etc.

Using a video screen also offers the possibility of trying to give actual fabric appearance rather than squares, which are really not suitable for knitted fabrics. Character generators¹⁵² are generally set for a 5x7 dot matrix. This should be ample for the development of loop shape and appearance which could be linked to give the fabric appearance.

Data storage with the use of a processor must be examined so a suitable system can be chosen. If a standard 8 bit microprocessor is used¹⁵³ then storage is laid out in bytes or 8 bit words. Usually this type of system offers about 32K bytes of RAM memory. Using a fairly simple arrangement of programming, the pattern can be stored in a two dimensional matrix form as variables, $A(X,Y)$, where X,Y represents the position of the pattern unit. The value of this unit (an 8 bit word) can then represent the colour being knitted at this particular point. This type of storage requires about 5 bytes per variable. Approximately 5,000 units of RAM could be utilised leaving 8K of RAM for processing. This would represent a pattern of approximately 70x70 stitches. This could be conveniently stored and

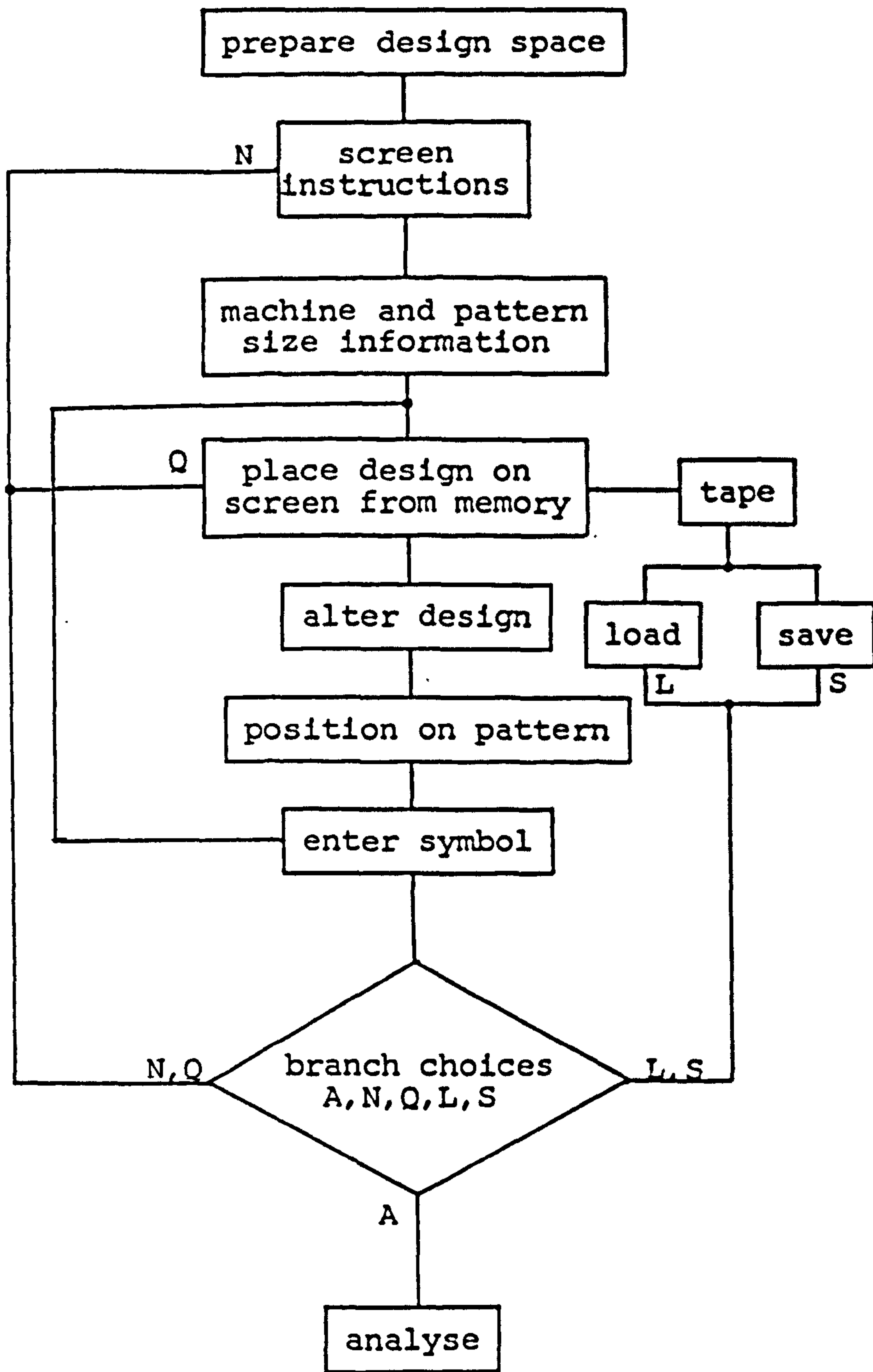


Figure 1.15 Flow chart for pattern preparation program.

analysed. However this is not a very large pattern area in terms of electronic needle selection jacquards. For large area patterns it is possible to use the actual memory layout in the microprocessor to represent the position in the pattern and the unit held in each bit to represent knit or miss. Using 24K bytes of RAM 192,000 bits are usable giving a pattern area of around 400x400. To do this increases the programming complexity but is nevertheless quite possible. It would thus seem that a moderate size 8 bit microprocessor would have suitable storage capabilities.

Analysis is primarily required to separate the pattern into L_{1000} , L_{1100} , L_{1001} and L_{1101} lengths which will give the basic yarn requirements. The pattern can then be examined for the bad structural units as dependent upon the number of colours used. Optimal feeder layout can be checked in terms of these units.

Figure 1.15 shows a flow chart of a pattern preparation system for small area three colour jacquards which gives design on screen facilities represented by one colour symbols on a Commodore PET¹⁵⁴ and offers analysis in terms of length groups. A Basic¹⁵⁵ listing of the program is given in Appendix 5.

This program is arranged in a question and answer form and allows a design to be developed in three colours within pre-set machine limitations. The pattern is laid out in a two dimensional matrix of variables in the memory and presented from this onto the screen. This allows the operator to present a "window" or section of the pattern on the screen while a larger pattern is developed. Normal screen resolution is used giving 40x25 characters. A section

16x16 is displayed while a pattern up to 48x48 can be developed in the memory. The position in the matrix (X,Y) is displayed in the top right corner of the screen. Resetting the bottom left point of the design is enabled by moving the position to be altered off the bottom or edge of the design area. The controls for the position being considered are altered from the number pad ; 8 and 2 giving up and down with 4 and 6 giving left and right. Each represents one stitch. The three colour characters are entered from the keys "F" , "G" and "H".

The program is arranged so that the pattern can be stored on tape, the "L" and "S" keys representing the Load and Save routines. Because variables are used for the pattern development this is a slow process using a standard cassette recorder but satisfactory using a "Floppy" disc unit.

Option "N" offers the chance to scrub the existing pattern and "A" leads to the analysis section. Here the units are scanned in an arrangement where the operator sets the knitting order of the three colours relative to the bottom left corner of the pattern. The units are separated into 1000 , 1100 , 1001 and 1101 types. For three colours this can be easily scanned for the various colour layouts. The data is displayed on the screen and can also be delivered to a printer. "Q" gives a return for display and alteration of the pattern.

The program runs quite slowly but offers a fairly simple system using a standard microprocessor for pattern development and analysis. Large improvements in storage efficiency could be achieved by using specific memory space and by even more by going to a bit by bit arrangement. If

large patterns were to be stored and analysed this would be necessary. Here it is considered sufficient to demonstrate a fairly simple use of standard equipment. Speed could be improved by using machine code routines to analyse and print the stored pattern to the screen but this would considerably complicate the programming.

To incorporate facilities for further structural analysis the 1101 groups must be arranged into double piqué and 2x1 rib repeats and the 1100 and 1001 into interlock and modified interlock combinations.

The analysis and pattern development has so far taken place in Basic in its standard form. With Basic the Commodore series 2000, 3000 and 4000 processors interrupt every 1/60 of a second to scan the keyboard with the CHARGET routine. This means that any layout must be slower than one character per 1/60 of a second to avoid timing problems. On 18 gauge knitting machines approximately 500 needles pass each feeder per second or each needle takes 2 ms to pass. The timing from Basic would then be unsuitable for needle selection data on this type of machine. Using machine code¹⁵⁶ the interrupt sequence can be disabled and the processor clocking speed of 1 MHz used to sequentially output data. This gives 1/1,000,000 s per unit. Thus within 2 ms or one needle space 500 bits of information can be passed. Hence it is quite possible to directly control all the needles on a knitting machine with 100 or more feeders. To present data in this form requires considerable external circuitry plus timing driven directly from the knitting machine. Nevertheless the actual possibility exists on this microprocessor.

Although microprocessor controlled knitting machines

with electronic needle selection exist, little data analysis is offered on these machines. The data is merely loaded and then presented. A great many machines exist with only mechanical needle selection which require their own set out procedures. The Commodore series microprocessors can be used for the procedures involved.

1.4 Conclusion

The primary aim of this work is to adequately control yarn length fed for all structures. As has been discussed, this is the single most important knitting parameter in any weft knit fabric. While positive feed is used for simple structures on circular machines, it can only be used in the case of very limited needle selection. Obviously the most important area to be considered on circular machines is that of patterned fabric production. On flat bed machines no successful and accepted system of positive feed exists for any fabric type. It is possible to calculate yarn requirements for all fabrics but difficult to set machines to these requirements without positive feed. Hence the first aim is to set up a positive feed system which can be used on all machines.

The second aim relates to the "state" of the fabric when it leaves the knitting machine. To enable easy fabric finishing this should be a state from which relaxation is easy. When a known length of yarn is used it is possible to predict the relaxed dimensions and aim to finish to these. Hence the fabric must be produced within its relaxable range. A linking system between yarn feed and fabric take-up is necessary to ensure that as one changes so does the other.

The obvious success of positive feed methods on circular machines has led to a greater use of weaker yarns. However, even with existing feed arrangements, stresses on the yarn are still quite high for certain fabrics. Matching the yarn feed to the actual demands in the knitting zone can reduce actual tension build up in this zone.

By reducing yarn stress, stress on the knitting elements will also be reduced. Thus from accurate feeding the load on the needles is decreased and hence their lifetime increased.

The above aims will be approached first by examining actual yarn movements on the knitting machine. A theoretical examination based on needle movements will be undertaken to determine yarn demand within the knitting zone. From this data it is hoped that it will be possible to ascertain requirements for a positive feed system and set up such a system.

Chapter 2

Yarn Movements

The most important factor in determining the knitted fabric's properties is the loop length or repeat length in the fabric. This chapter will examine how this length of yarn is drawn or fed into the fabric structure. It is essential that both length and tension be considered. From this it is hoped that a means for an improved feed system can be seen.

2.1 Knitting Machine and Yarn Delivery Speeds

One of the most important areas of yarn movement is the delivery rate at which the yarn is required. This is related to the knitting machine speed and to the relative lengths required for the various structures.

The circular knitting case is considered first. Here there are basically three types of machines: those with no needle selection, those with limited needle selection and jacquard machines. For the first type a typical speed would be 18 rpm for a 28 gge machine¹⁵⁷. This may be considered as approximately 900 needles per second or 1.1 ms per needle passing each feeder. The second type can reach speeds as high as 28 rpm for a 28 gge interlock machine¹⁵⁸. This gives 1080 needles per second past each feed point on each bed, or 0.9 ms per needle pair. These machines are usually provided with constant speed positive feed units. For machines which incorporate patterning such speeds cannot be achieved and it is normal to run an 18 gge machine at a maximum speed of 20 rpm⁹³. This gives approximately 560 needles per second past each feed point on each bed or 1.8 ms per needle pair.

Table 2.1

Comparison of yarn speeds for various machine types. For the flat and full fashion cases the direction of carriage movement is indicated by 'T' for towards and 'A' for away from the feeder.

Machine			Gauge (needles /inch)	No.Needles per Unit	Time/ Unit (ms)	Yarn Speed (m/min)					
						Unit	L ₁₀₀₀	T	A	T	A
		rpm	diam. (in)								L ₁₁₀₀
											L ₁₁₀₁
Plain		20	30	1	1.1	180					
Interlock		28	30	2	0.9	200					
Jacquard		20	30	4	3.6		85			175	220
Jacquard		26	30	4	4.2		105			220	275
		traverse /min	width (in)			T	A	T	A	T	A
Flat		32	80	4	4.2		40	144	126	228	162
Flat		32	80	4	8.0		40	144	126	228	162
Full Fashion		50	34	1	2.2	108	168				

Flat bed knitting machines are normally of a coarser gauge than circular machines and a maximum speed of 30 traverses per minute for a 12 gge machine is possible over an 80 inch bed width¹⁵⁹. This results in the feed point passing 480 needles per second on each bed or 2.1 ms per needle. Here the machine speed is approximately the same whether or not patterning is provided on the machine. For full fashioned machines 50 courses per minute are possible (on a 34 inch width) on a 16 gge machine¹⁶⁰. This gives 450 needles per second relative to the feeder or 2.2 ms per needle.

As discussed previously the bird's eye backed jacquard fabric can be broken down into three length groups L_{1000} , L_{1100} and L_{1101} , which occur over a four needle repeat.

On a flat bed machine the yarn delivery speed depends upon the cam carriage movement and hence feeder movement as well as the yarn requirements of the structure. When the carriage is moving away from the side where the yarn is fed a length equal to the carriage movement must be drawn from the cone in addition to the length required in the fabric. When the carriage moves towards the feed side the movement of the feeder makes extra yarn available for knitting and so the movement distance is subtracted from the yarn requirements.

The yarn speed requirements for all the machines discussed are shown on Table 2.1. Here the speeds are shown for each length unit in the jacquard case and for each direction for the flat beds. All the speeds given for both the flat and circular cases are the average yarn speeds.. These correspond to the delivery rate required from a

constant speed feed device for the specific units.

2.2 Model of Yarn Movement

During the formation of any unit, yarn is required at a variable rate which is dependent upon the movement of the loop forming elements. To reduce tension variations the actual requirements will have to be followed as closely as possible by a yarn feed system. The needle movement and its effect on how yarn is drawn into the fabric are now considered.

2.2.1 Theory of Yarn Movements

As the needles move down the cam they take on yarn and draw this yarn into the structure. The demand is therefore related to this needle movement. The prime variables are the knock over depth (the distance the needle moves below the verge) on each needle bed used, the distance between the needle beds and the knock over and uplift cam shapes. The cam shapes are set by the machine builder and the other variables are easily set by the knitter. Another variable which will affect yarn movement is the timing. Non-synchronous timing is however used only in the case of unpatterned fabric, patterned fabrics generally being produced synchronously.

The needle movements, as controlled by the variables, will be examined to clarify their effect upon dynamic loop formation. A simplified approach is used. The length of yarn held in the loop section on each needle is considered to be given by that of a straight line from the edge of the trick to the inside of the hook of the needle plus another straight line from here to the opposite trick as shown in

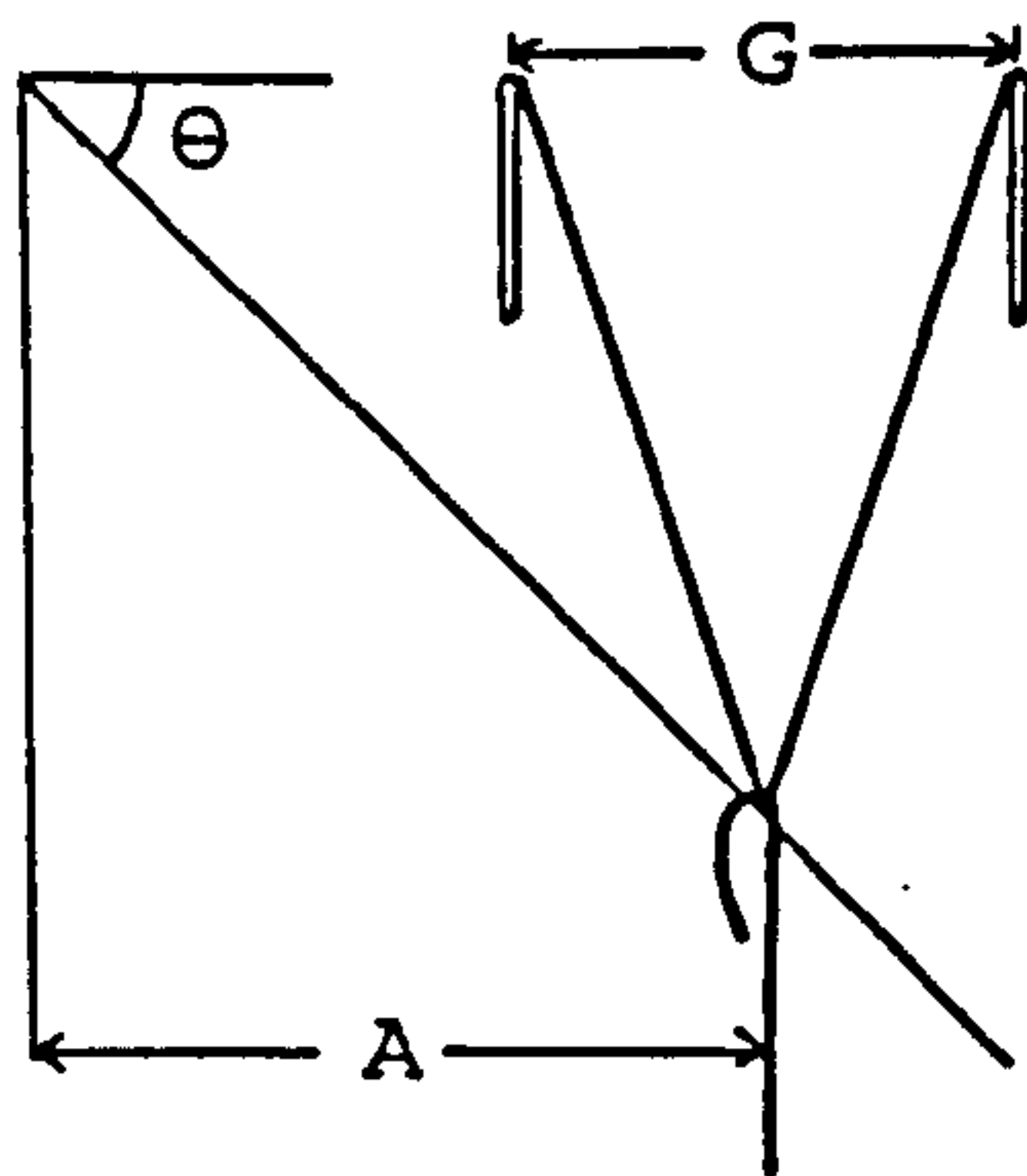
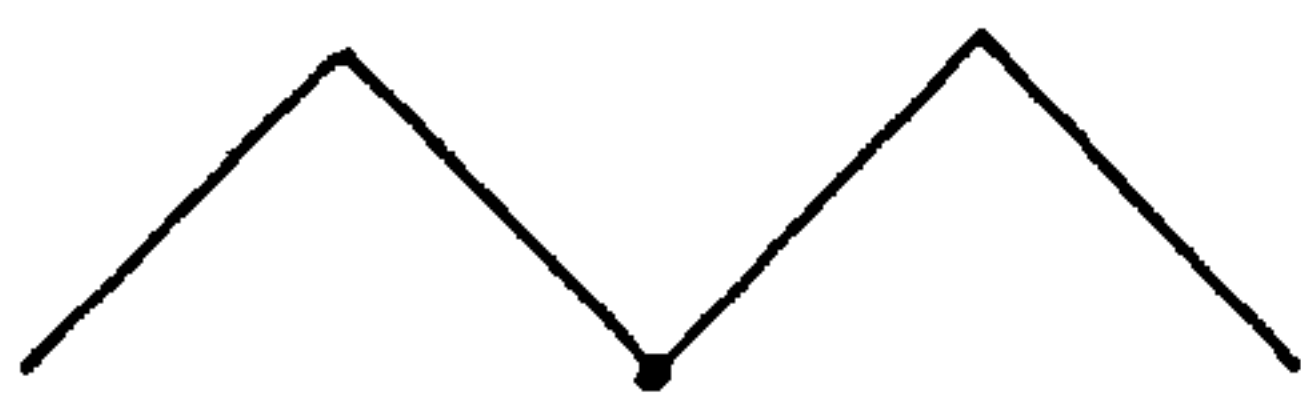
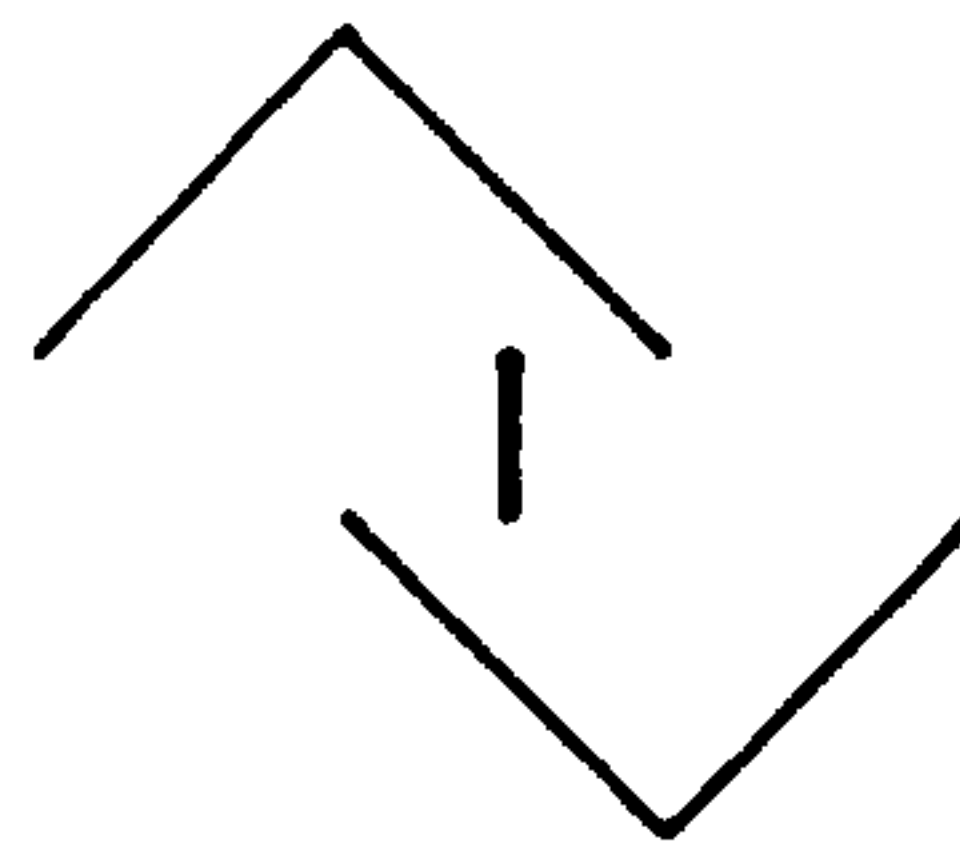


Figure 2.1 Diagrammatic representation of the simplified approach used to estimate the amount of yarn in the loop section.



(a) $C=0$



(b) $C=D-G/2$



(c) $C = \sqrt{D^2 - (G/2)^2}$



(d) $C=G$

Figure 2.2 Representation of the four crosslink arrangements as used in the yarn movement model. The length of each arrangement is shown, with D representing the bed separation and G the needle spacing.

Figure 2.1. The length, L, held at a point horizontally distant A into the knitting zone is thus

$$L = 2 \sqrt{(G/2)^2 + (A \tan \theta)^2}$$

for a straight cut cam of angle θ with a needle spacing of G. It is assumed that the yarn is inextensible and has no thickness. This model, which has previously been used by Knapton and Munden^{74,92} in their studies of loop formation for plain fabric, is a great simplification of the actual loop form^{107,161,162}. However, further studies by Knapton and Lau¹⁰⁸⁻¹¹⁰ concluded that no more information was gained by using a more complex model as many assumptions still have to be made.

For jacquard fabric produced with bird's eye backing four different types of links between one loop and the next are possible¹³⁸. These are shown in Figure 2.2. Case (a) is between two loops formed successively on the same bed and the link distance is considered to be zero as in plain fabric. Case (b) is the cross over found in 1x1 rib fabric. This is considered to be equivalent to the needle bed spacing minus half a needle space. The half needle space is subtracted to account for the fact that the loop edges are not opposite each other and so the loop cannot really form at the edge of the trick. Case (c), between the first dial needle and the second cylinder needle, is the hypotenuse of a right angle triangle and is given by the square root of half the needle space squared plus the distance between the needle beds squared. The fourth case, (d), is the loop separation when half gauge plain is produced and is equal to one needle space.

The total length held is that of the loops held on

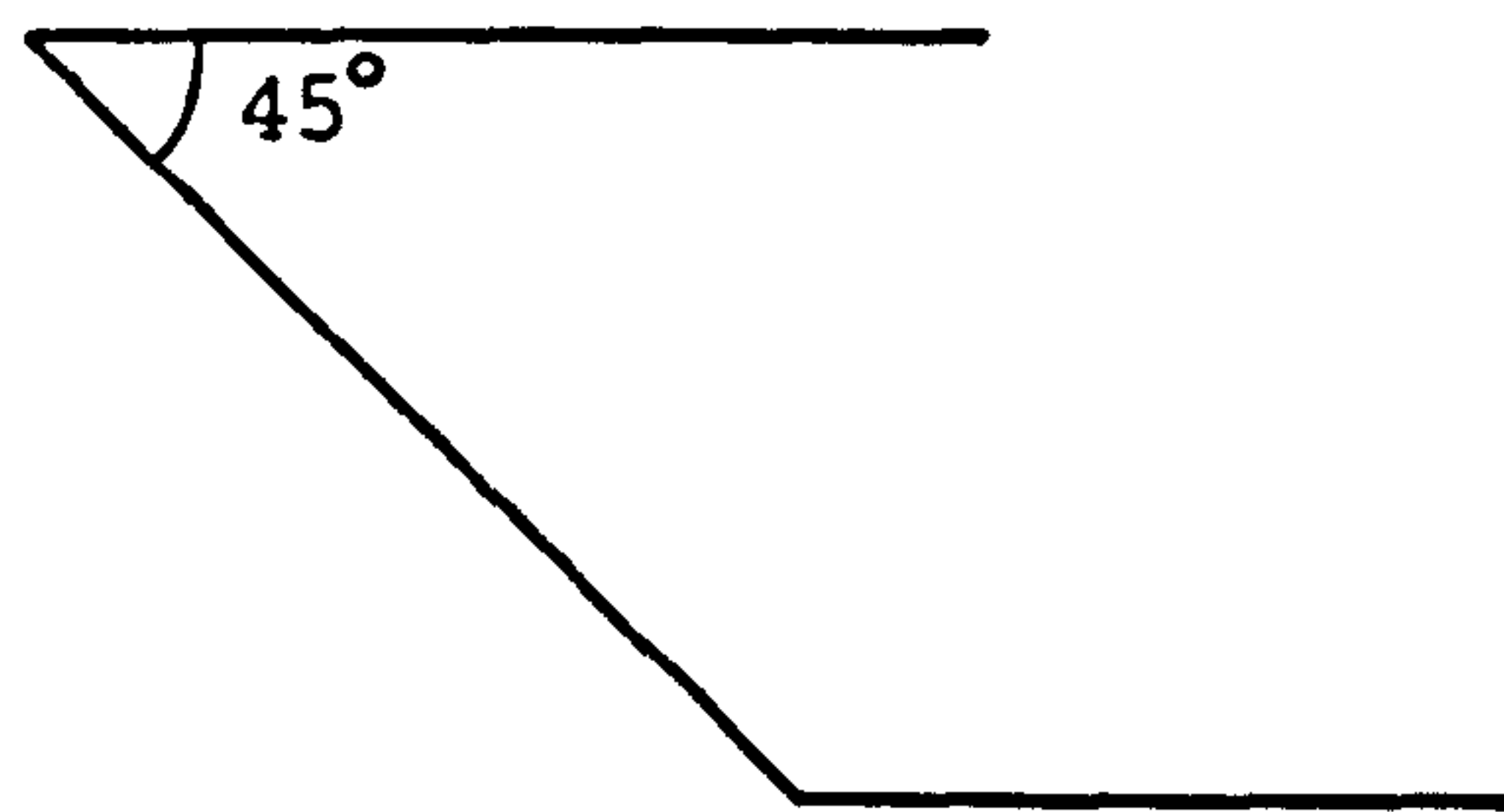


Figure 2.3 Flat bottom 45° straight cut cam.

each needle plus the cross link lengths. This length is further broken down by separating the effect of machine rotation from the loop length and crosslink calculations. This means that the straight line length through the knitting zone is subtracted from the lengths crossing between the beds and forming the loops. Thus the total length is considered as the straight line length plus the crosslinks and loops over this length. The loop length is altered by the needles moving down the cam; the straight line length is altered by the machine rotation and the remaining cross link length is introduced as each new loop forming needle enters the knitting zone. These three lengths can then be calculated for each needle position. The effect of machine rotation is separated to enable the later examination of flat bed machines where cam carriage movement must be introduced.

First the case is considered where a flat bottom 45° straight cut cam as shown in Figure 2.3 is used. This type of cam will fully limit robbing back, that is, after the needle passes the knock over point the same amount of yarn remains on the needle as it leaves the knitting zone. Yarn is only fed from the feeder and not back from within the structure. For each position of the knitting machine the position of all the needles can be determined and the length held calculated. For any change in machine position the new needle positions can be calculated and hence the length required to be fed into the structure is found. Thus it should be possible to determine the feed requirements of all the elements within the jacquard structure.

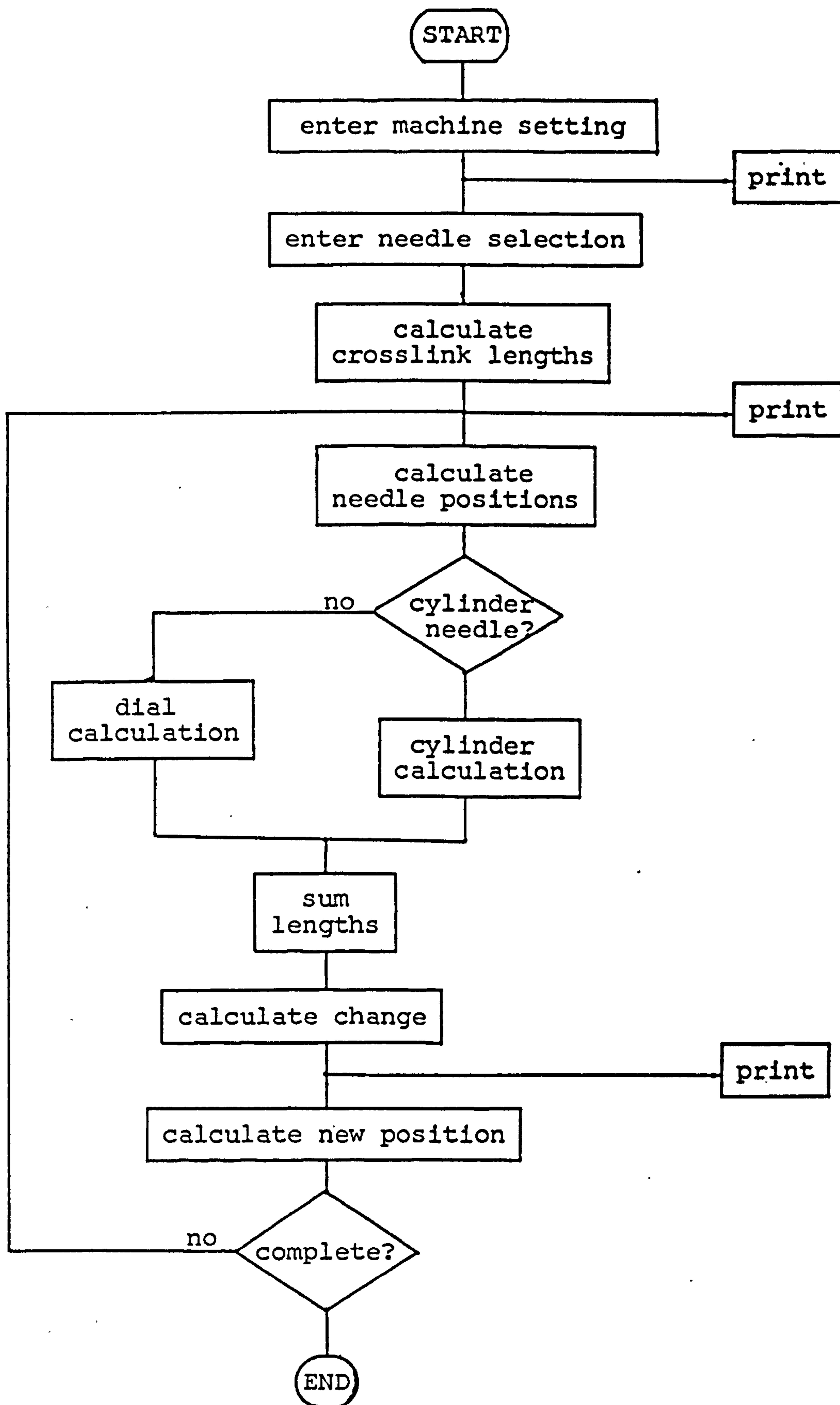


Figure 2.4 Yarn movement model program flow chart

2.2.2 Computer Implementation of Yarn Movement Theories

To implement the yarn movement model calculations a Commodore PET¹⁵⁴ microprocessor is used. A flow chart of the program is shown in Figure 2.4. This program is laid out in a form such that the information of machine gauge (G), knock over depths for both needle beds (KOC and KOD), the distance between the needle beds (D) and the number of needles in the repeat (A) can be entered via the keyboard. Following this the needle selections are entered as 1 when the needle knits and as 0 when the needle misses into an array N(N) where N is the needle number and N(N) gives the selection. The needles are numbered up from 0, 0 representing the first dial needle, 1 the first cylinder needle and so forth. Thus all even numbered needles are on the dial and all odd numbered needles are on the cylinder. From this selection data the sequence of needle data is used to calculate the crosslink, C(N), where N is again the needle number, which must enter with each needle entering the zone. The repeat length within the structure is then calculated based on the values calculated for when each needle in the repeat holds its maximum length, that is, when the needle is at knock over. All the crosslinks are added in. The positions of the needles within the zone are then calculated.

Thus over these needles the position of each needle on the cam is found and the length of yarn held in the loop, L(N), is calculated. The needles are split into cylinder and dial needles for this calculation to allow for different knock over depths on each bed. The total length is then calculated by adding loops and crosslinks of the needles within the zone. This length is retained and then a new

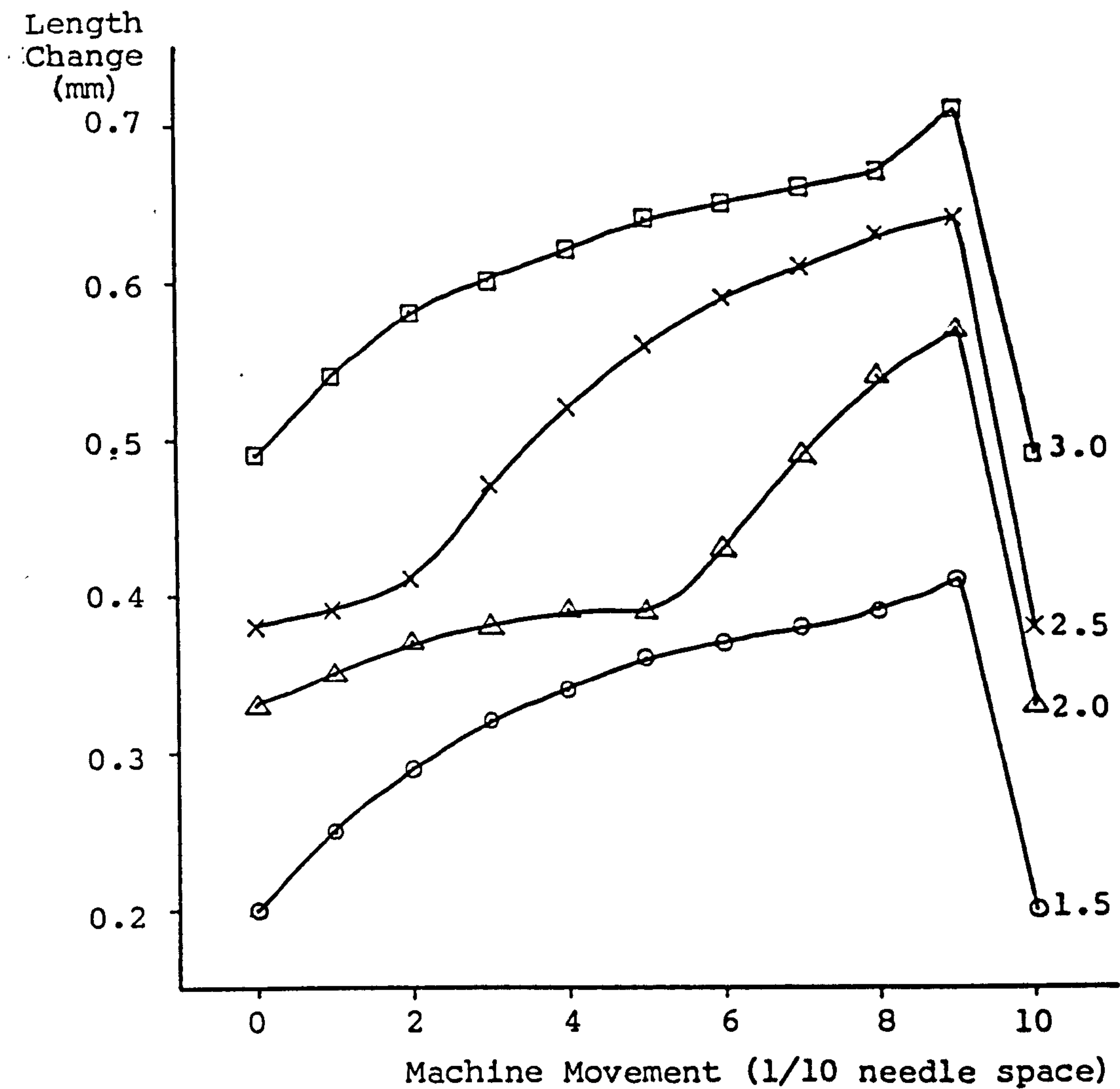


Figure 2.5 Yarn length change v. machine movement for plain fabric with no robbing back knitted on an 18 gge machine with a 45° straight cam. The knock over depth in millimetres is shown at the end of each curve.

position is obtained by stepping the machine one tenth of a needle space. The calculation is then repeated with the machine rotation added. Needles leaving the knitting zone are assumed to hold their maximum length and maintain it. Hence the length change for each machine movement can be calculated. This is printed out along with data as to which needles are at the beginning of the zone and the first needle from which the calculation is based.

A listing for this program in Basic is shown in Appendix 6.

2.2.3 Single Knit

Calculations from the yarn movement model are considered first for single knit fabric. Here only one needle bed is used which knits on all the needles. No crosslinks exist in this fabric. The fabric is considered in forms with and without rob back.

2.2.3.1 Results from the Basic Model

The results for single knit fabric produced on an 18 gge machine at knock over depths of 1.5, 2.0, 2.5 and 3.0 mm are shown graphically on Figure 2.5 and tabulated in Appendix 7. The predicted length change is plotted against movements of one tenth of a needle space (0.14 mm). In the first section of Table 2.2 results are shown for the total yarn drawn into the structure and for variation in demand rate within the cycle. For the 1.5 mm knock over depth it can be clearly seen that the demand varies greatly for the various units within the repeat cycle; from 0.20 mm or just over that demanded by machine rotation to 0.41 mm, a

Table 2.2

Predictions of yarn length and variation for the plain knit 18 gge fabric at various knock over depths and conditions of rob back. The variation is presented as the difference between the maximum and minimum length per tenth needle space expressed as a percentage of the mean length per tenth needle space.

Rob Back Condition	Knock Over (mm)	Total Length (mm)	Max-Min (mm)	Variation (%)	Rob Back (%)
no rob back	3.0	6.16	0.22	36	0
	2.5	5.20	0.27	52	0
	2.0	4.24	0.24	57	0
	1.5	3.32	0.21	63	0
unrestricted	3.0	3.48	0.23	66	45
	2.5	2.57	0.29	113	50
	2.0	1.84	0.33	179	58
	1.5	1.43	0.39	272	60
half restricted	3.0	4.84	0.22	45	22
	2.5	3.90	0.27	69	25
	2.0	3.04	0.27	89	29
	1.5	2.40	0.31	129	30

variation of 63% of the mean demand value. This represents the cycle for a single needle moving down the cam. The knock over depth here is approximately equal to the needle spacing on the machine. The slight increase near the end of the cycle (at the ninth needle position) corresponds to a second needle just starting to move down the cam before the first needle has passed the knock over point and left the knitting zone.

For the slightly increased knock over of 2.0 mm the difference between the effects of one and two needles moving down the cam can clearly be seen as a transition on the curve. Because the needle enters the zone relatively earlier and the program calculates from a fixed distance from the knitting zone, the beginning of the curve represents the single needle at approximately the same depth as the end of the 1.5 mm knock over curve. Although this curve is in two distinct sections the variation between maximum and minimum demand is only between 0.57 and 0.33 mm or 57% of the average yarn demand, a slight reduction from the 63% variation of the 1.5 mm knock over case.

As the knock over depth is further increased to 2.5 mm the curve becomes dominated by the effect of the two needles moving down the cam, again having two distinct sections. The variation within the cycle is between 0.67 and 0.38 mm or 52% of the average demand. Still further increasing the knock over depth to 3.0 mm results in a curve almost completely having two needles moving down the cam but with a small section where three needles are concerned. The variation within the cycle here is from 0.71 to 0.49mm, a reduction from that previously considered to 36%. This curve takes on a very similar form to that with only one needle

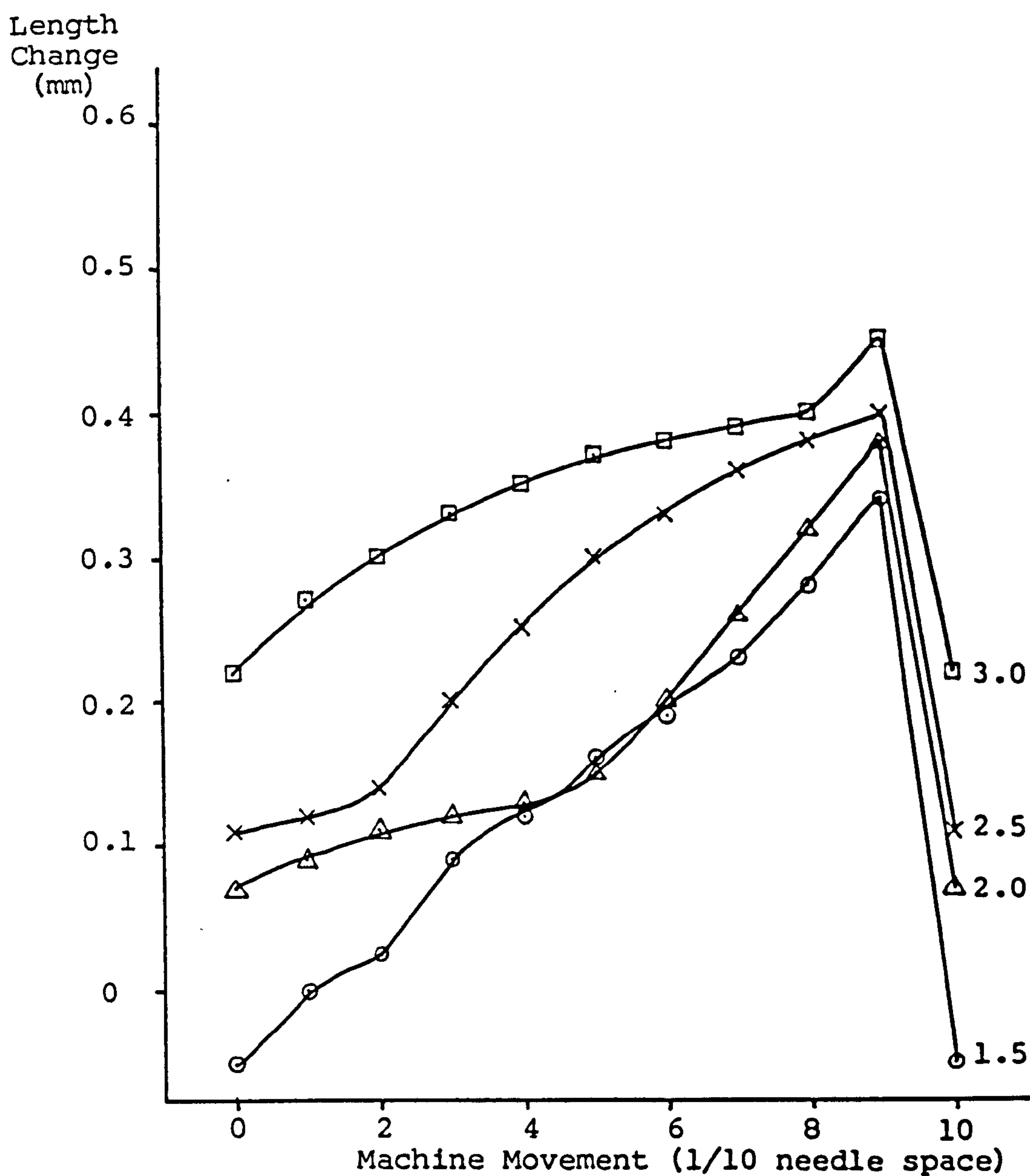


Figure 2.6 Yarn length change v. machine movement for plain fabric with unrestricted robbing back from one loop as knitted on an 18 gge machine with a 45° straight cam. The knock over depth in millimetres is shown at the end of each curve.

on the cam but of course at a higher input rate.

2.2.3.2 Introduction of Rob Back

Studies^{74, 92} have shown that yarn is not only drawn into the knitting zone from the feed point but is also drawn back into the structure from previously knitted needles. If the program is modified to allow yarn to be drawn from the previously knitted loop as this needle moves up under control of the upthrow cam, the effect of rob back can be examined.

The needle which has previously knitted is identified and the amount of yarn held by this needle on the cam calculated for a symmetrical up down cam system. It is assumed here that the upthrow cam is 45° and straight cut. The reduction in yarn now held on this needle compared to its previous position has effectively been drawn back into the structure. The crosslinks are considered to be set by machine geometry and cannot contribute to the yarn robbed back. The modifications in the program to do this are given in Appendix 6.

The results for the calculation with robbing back allowed freely from one needle are shown on Figure 2.6 and total yarn drawn on Table 2.2. The complete results are given in Appendix 7. Considering first the 1.5 mm knock over depth results it can be seen that the total yarn drawn into the structure is reduced to 1.43 mm from 3.32 mm or a 60% reduction. This figure is in keeping with that found by Knapton and Munden⁷⁴ using a calculation based on tension balance within the structure. This was their maximum value for robbing off one needle and required a high input tension.

However an anomaly does exist within this calculation

where a negative value is found indicating a desire for yarn to be drawn out of the structure back to the feed point. This of course cannot happen in most cases. However on many machines a stop motion which does act somewhat as a two way active storage element is used. This may enable an effect of this type to occur. It is more probable that this negative demand results in less yarn being drawn back in the structure due to a change in the internal balance conditions. This is however, a point of minimum demand and must be carefully considered in terms of maintaining adequate control over the yarn movement into the needle hook. With a 1.5 mm knock over one needle moves down the cam while another needle moves up the other side. The variation in demand is 0.39 mm between maximum and minimum points or 272% of the average demand which is greater than in any of the non rob back cases.

As the cam depth is increased to 2.0 mm the negative demand disappears as here for most of the cycle two needles are moving down the cam and the robbing back is considered to take place over one needle only. Again about 60% of the yarn length is robbed back. The variation within the cycle is 0.33 mm, or 179%, still a substantial increase over the non rob back cases. The curve becomes dominated by the two needles moving down the cam at a knock over depth of 2.5 mm and the rob back is reduced to approximately 50%, the demand variation being likewise reduced to 0.29 mm (113%). A 3.0 mm knock over depth gives a rob back of 45%, the rob back being related to the number of needles on the cam. The curves in all cases are extremely similar in form to the cases where no rob back occurs, showing only a shift in level.

An interesting aspect can be seen by comparing the

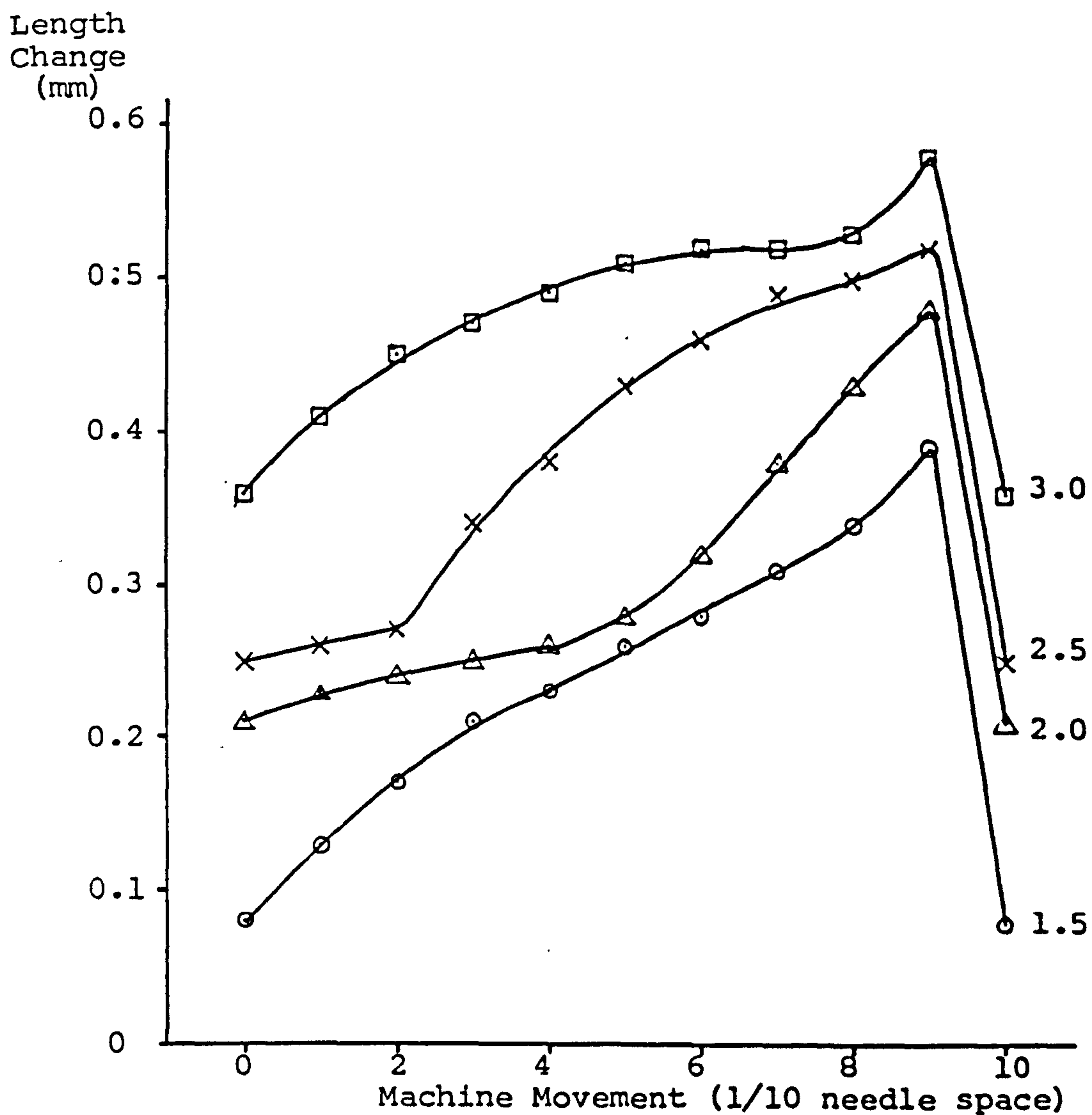


Figure 2.7 Yarn length change v. machine movement for plain fabric with rob back restricted to half the length available from one loop as knitted on an 18 gge machine with a 45° straight cam. The knock over depth in millimetres is shown at the end of each curve.

1.5 mm knock over without rob back with the 3.0 mm knock over case with rob back which result in the same amount of yarn being drawn into the structure. Here the demand curves are also remarkably similar and so it seems that basically the same demand within the single knit is required to give the same amount of yarn within the structure independent of the movement within the knitting zone of yarn being robbed back.

Limits on the amount of yarn being robbed back can be introduced into the calculations by either modifying the cam shape or restricting how much yarn from the previous needle is free to be robbed back. If only half of this amount of yarn is considered available, then a series of curves as shown in Figure 2.7 and results as presented in Table 2.2 and Appendix 7 are produced.

Here the rob back varies from 30% for a knock over of 1.5 mm to 20% for a knock over of 3.0 mm. This represents the more normal case as found by Knapton and Munden⁷⁴. Again the curves are the same form. Here a knock over of 2.5 mm gives a similar demand curve, and amount of yarn drawn, to the unrestricted rob back with a knock over of 3.0 mm which, as previously stated, is similar to that with no rob back and a knock over of 1.5 mm. The differences here are related to the number of needles in the knitting zone.

2.2.4 1x1 Rib

In the consideration of two bed structures the most important element to be introduced is the effect of the yarn crossing from one needle bed to the other. Another difference in the 1x1 rib is that for a given knock over depth on both beds twice the number of needles are in the knitting

Table 2.3

Predictions of yarn length and variation for the 18 gge 1x1 rib fabric with various knock overs and conditions of rob back. The needle bed separation is 1 mm and knock over depth is the same on both beds.

Rob Back Condition	Knock Over (mm)	Total Length (mm)	Max-Min (mm)	Variation (%)	Rob Back (%)
no rob back	3.0	12.92	1.14	88	0
	2.5	10.98	1.08	91	0
	2.0	9.07	0.94	104	0
	1.5	7.23	1.19	165	0
unrestricted	3.0	10.20	1.14	112	20
	2.5	8.30	1.08	122	27
	2.0	6.50	0.94	145	28
	1.5	4.48	1.22	252	33
half restricted	3.0	11.54	1.14	100	10
	2.5	9.64	1.07	106	13
	2.0	7.79	0.94	125	14
	1.5	6.03	1.20	200	17

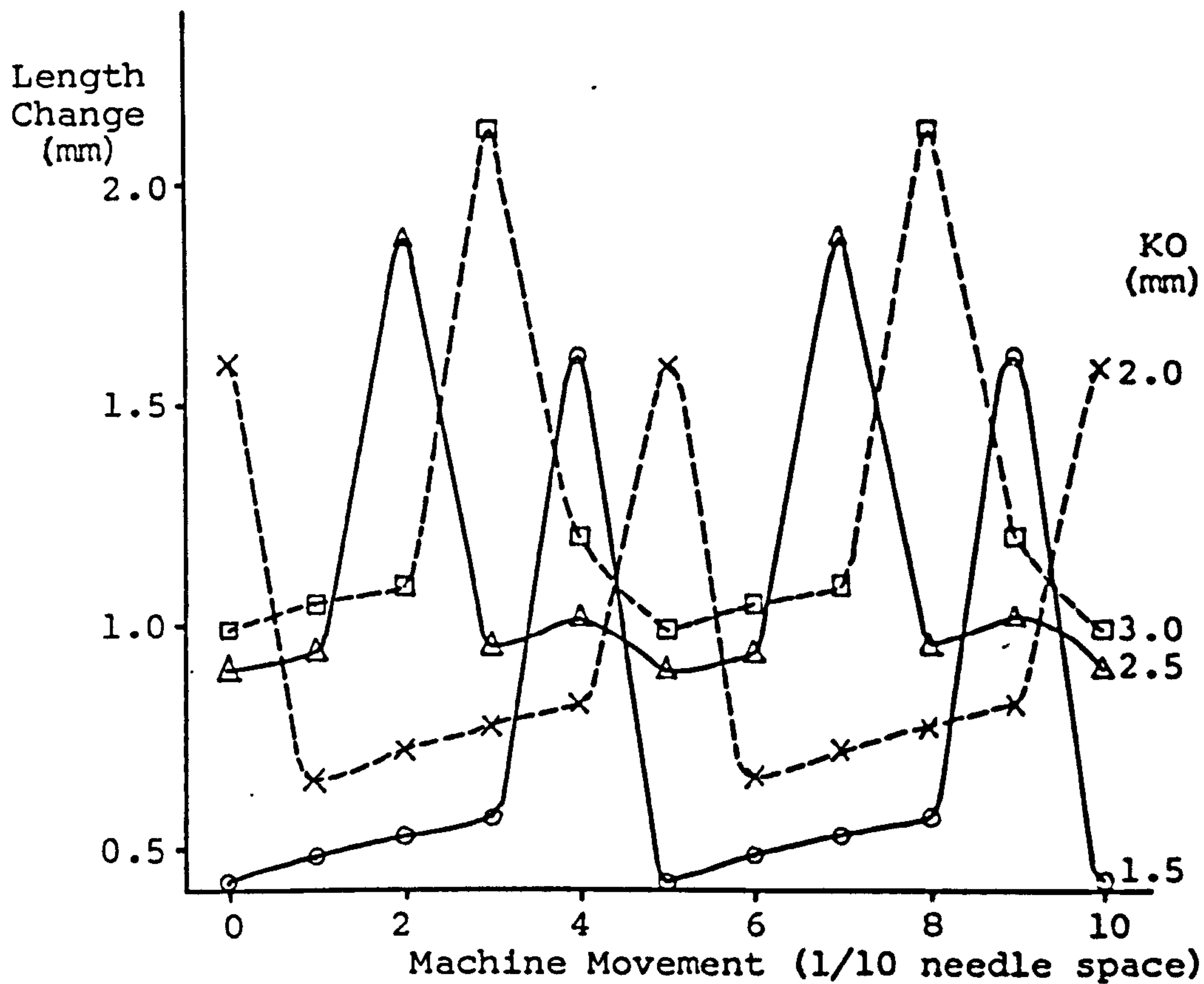


Figure 2.8 Yarn length change v. machine movement for 1x1 rib with no rob back knitted on an 18 gge machine with a 45° straight cam and 1 mm bed separation.

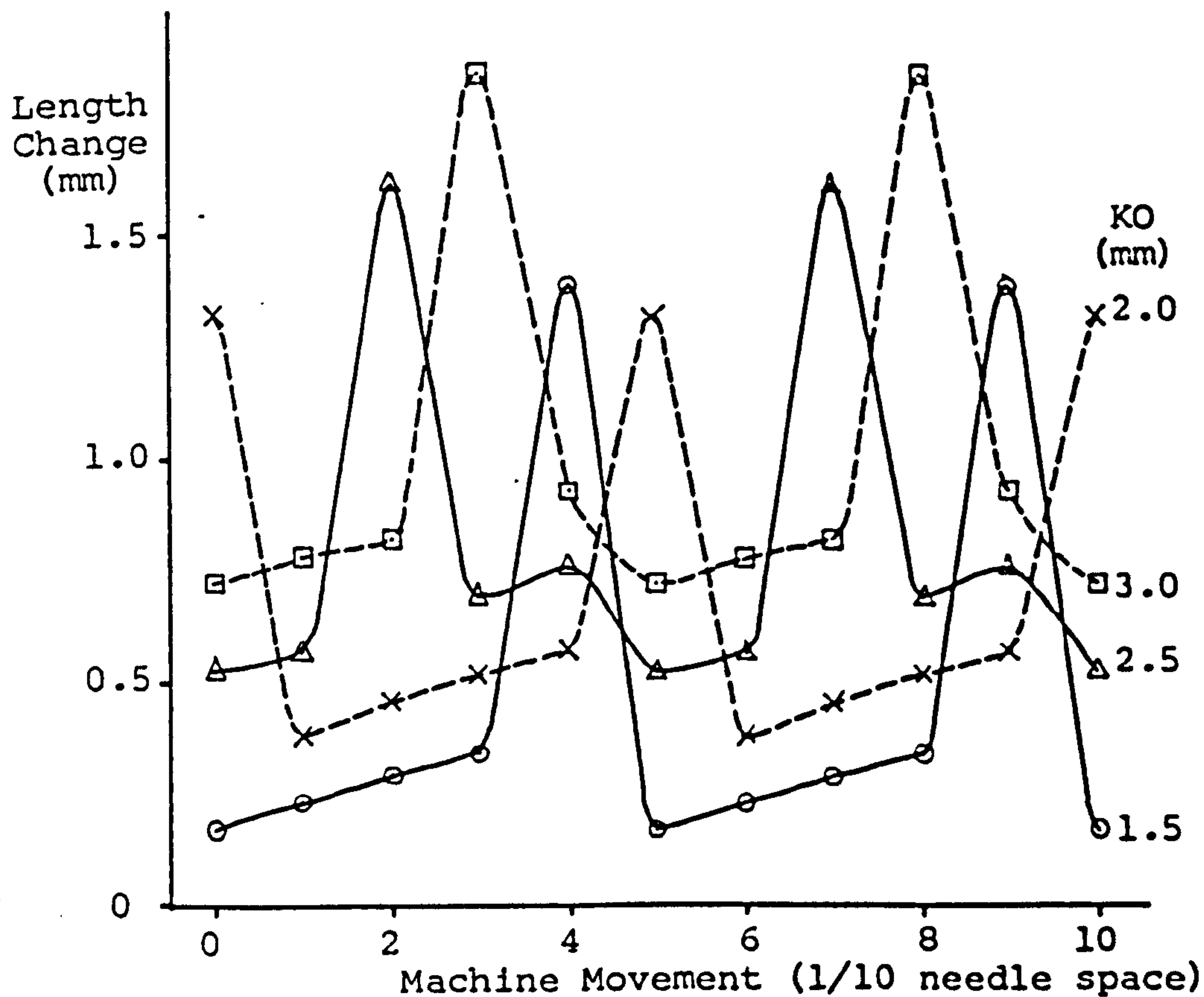


Figure 2.9 Yarn length change v. machine movement for 1x1 rib with unrestricted rob back. Other conditions are as for Figure 2.8.

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zone compared with the plain knit case.

The results for 1x1 rib with no rob back are given in Table 2.3, Figure 2.8 and Appendix 8. The variation within the cycle seems to be very dependent upon the position on the cam of the needles when the cross over between the needle beds occurs. For the 1.5 mm knock over (on both beds) the variation is 1.19 mm while at the larger knock over of 2.0 mm the variation is reduced to 0.94 mm (165% to 104% of the mean demand), although the maximum demand rates are about the same. In all the 1x1 rib fabric, variation within the cycle is far greater than for the single knit. The results given are for a 1 mm distance between the needle beds which would be about the minimum possible on an 18 gge machine. If this distance is increased the curves would show an increase in the size of the peaks which represent the demand for yarn as it crosses the needle beds.

When rob back is introduced (Figure 2.9, Table 2.3 and Appendix 8) it can be seen that the actual percentage of yarn robbed back is much less than for single knit. Here again yarn is permitted to be drawn freely from the first knitting needle past the knock over point as dictated by its upward movement. As observed for the single knit case the amount of rob back reduces as more needles are introduced into the knitting zone. This would seem to be the reason for the reduced rob back in the single knit as knock over depth is increased. It must be remembered that rob back can only take place from the loop section of the fabric and so the crosslink length will remain the same. As in the 1x1 rib a large percentage of the yarn is in the crosslinks. This will affect the amount which can be altered

Table 2.4

Unit lengths and length ratios predicted by the no rob back model at various settings. All lengths and settings are shown in millimetres.

KOC	KOD	D	L ₁₀₀₀	L ₁₀₀₁	L ₁₁₀₁	$\frac{L_{1001}}{L_{1000}}$	$\frac{L_{1101}}{L_{1000}}$	$\frac{2L_{1100}}{L_{1101}+L_{1000}}$
1.0	2.0	2.0	5.65	10.10	11.73	1.78	2.16	1.16
2.0	2.0	2.0	5.65	11.89	15.31	2.10	2.71	1.14
2.5	2.0	2.0	5.65	12.85	17.22	2.27	3.05	1.12
2.0	1.0	2.0	3.86	10.10	13.52	2.61	3.50	1.16
2.0	2.5	2.0	6.61	12.85	16.27	1.95	2.46	1.13
2.0	2.0	1.0	5.65	10.00	13.31	1.77	2.36	1.05
2.0	2.0	2.5	5.65	12.88	16.31	2.28	2.89	1.17
2.5	2.5	2.0	6.61	13.80	18.19	2.09	2.75	1.12

by rob back. As found for the single knit case the form of the demand curve to draw the same amount of yarn with and without rob back is extremely similar. Again the same order of variation is found within the cycle. Because of the much reduced rob back, the repeat length at 3.0 mm is about the same as that at a knock over of 2.5 mm without rob back.

If the amount of rob back is restricted to half that available from one needle it can be seen from Table 2.3 that rob back is only in the range 10 to 17%. The variation here is again high, being greater than 100% for all the settings considered. As the form is so close to the other two cases considered a graph is not presented but the results are shown in Appendix 8.

2.2.5 Jacquard Structures

The four units 1000, 1001, 1100 and 1101 which appear in the bird's eye backed jacquard can be seen to be a combination of the cases discussed as plain and 1x1 rib. The same model of yarn movement will be used for the calculations.

2.2.5.1 Effect of Machine Settings on Yarn Distribution

Table 2.4 shows the predicted repeat values for the length groups L_{1000} , L_{1001} , L_{1100} and L_{1101} with no rob back at various settings. L_{1001} and L_{1100} in the no rob back case are the same length and so only the L_{1001} results are shown.

To examine the effects of knock over depth on the cylinder (KOC), knock over depth on the dial (KOD) and needle bed separation (D), each of these settings was varied

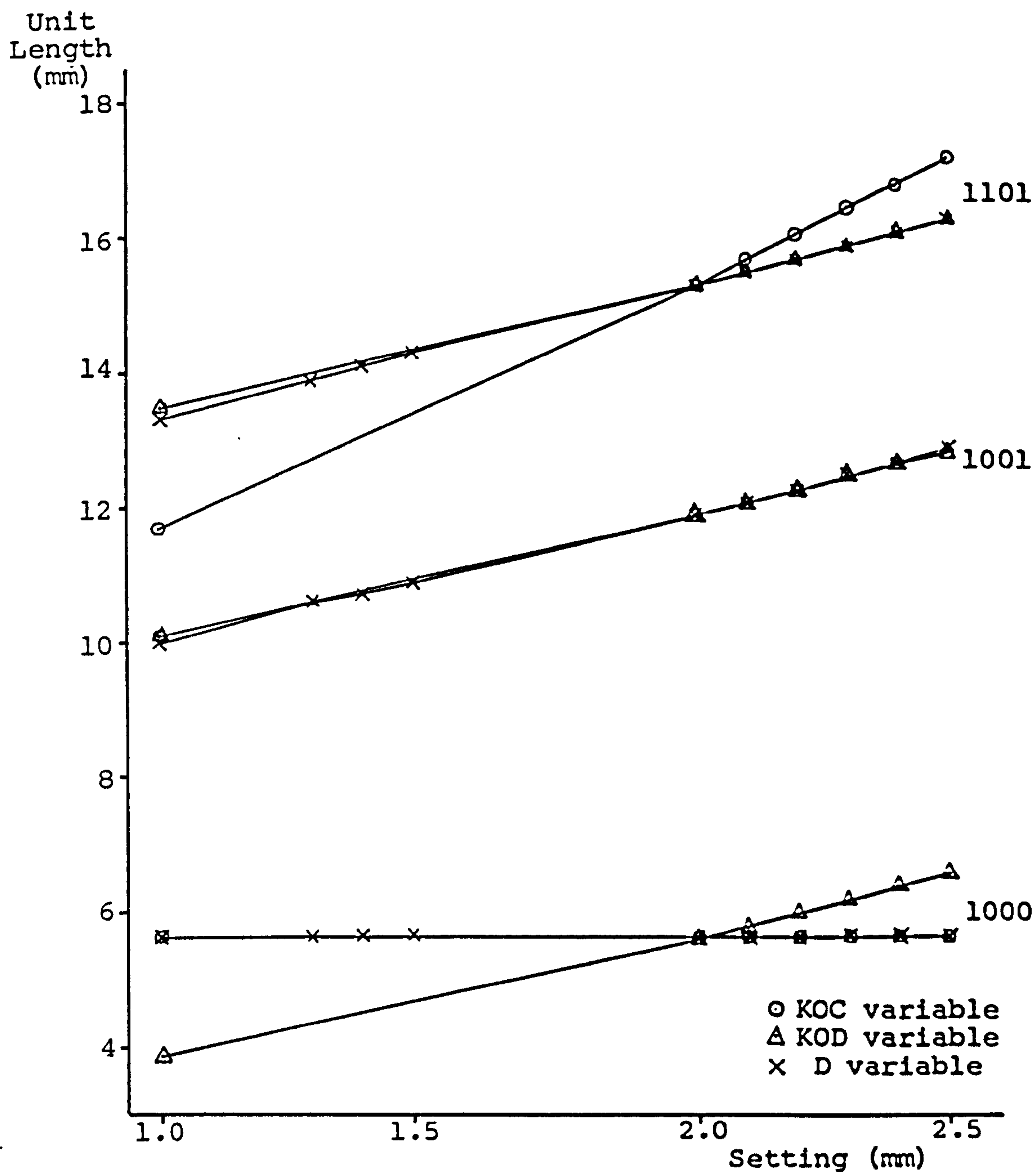


Figure 2.10 Jacquard unit length v. setting for 18g fabric with no rob back. When a setting (as indicated by point type) is varied, the other two settings are held constant at 2 mm. The unit is indicated at the end of each group of curves.

Table 2.5

All lengths are in millimetres.

KOC	KOD	D	L ₁₀₀₀	%Rob Back	L ₁₀₀₁	%Rob Back	L ₁₁₀₁	%Rob Back	L ₁₁₀₁	%Rob Back	$\frac{L_{1001}+L_{1100}}{L_{1001}+L_{1000}}$	$\frac{L_{1001}}{L_{1000}}$	$\frac{L_{1101}}{L_{1000}}$
unrestricted rob back													
2.0	2.0	1.0	2.82	50	5.87	41	5.87	41	8.32	26	1.05	2.08	2.95
2.0	2.0	2.0	2.82	50	7.77	35	7.77	35	10.32	30	1.18	2.76	3.66
2.5	2.0	2.0	2.82	50	7.97	38	8.68	31	11.19	35	1.18	2.81	3.97
2.0	2.0	2.5	2.82	50	8.75	32	8.75	32	11.32	32	1.25	3.10	4.00
2.0	2.5	2.0	2.82	60	8.68	31	7.97	38	11.23	32	1.18	3.08	3.98
2.5	2.5	2.0	2.82	60	8.46	38	8.46	38	12.89	28	1.08	3.00	4.57
1.5	1.5	2.0	2.84	40	7.06	30	7.06	30	8.26	35	1.27	2.50	2.93
half restricted rob back													
2.0	2.0	1.0	4.29	25	8.88	20	8.88	20	10.88	13	1.16	2.10	2.53
2.0	2.0	2.0	4.29	25	9.78	18	9.78	18	12.88	15	1.14	2.28	3.00
2.5	2.0	2.0	4.29	25	10.46	19	10.66	15	14.61	18	1.13	2.44	3.41
2.0	2.0	2.5	4.29	25	10.90	16	10.90	16	13.88	16	1.20	2.54	3.23
2.0	2.5	2.0	4.73	30	10.66	15	10.46	19	13.82	16	1.14	2.25	2.92
2.5	2.5	2.0	4.73	30	11.44	19	11.44	19	15.53	14	1.13	2.42	3.27
1.5	1.5	2.0	3.78	20	8.61	15	8.61	15	10.40	18	1.16	2.27	2.75

in turn from 1.0 to 2.5 mm while the other two variables were held constant at 2.0 mm. The results are shown on Figure 2.10. This range of settings from 1.0 to 2.5 mm is representative of the usual 18 gge case.

For L_{1000} it can be seen that only KOD is predicted to have an effect, with KOC and D having no effect. L_{1001} is affected similarly by all of the variables while L_{1101} is affected more by KOC but the same by KOD and D. The greater rate of change of L_{1101} with KOC would be expected since in this unit two loops are formed on the cylinder and only one on the dial.

If the effect of these settings on the ratios between the various units and hence the balance within the complete jacquard fabric is considered, D is seen to have the greatest effect. As discussed in section 1.3.2 (page 34) only under very low values of this parameter would the ideal situation exist. In all other cases the interlock groups are produced with a more open structure than the 2x1 rib and half gauge plain combination. KOD also has an effect on the relative distribution between the units, an improved arrangement occurring for high values of this parameter. KOC has a small effect on this distribution. With changes in KOC the relationship between L_{1001} and L_{1101} remains the same and L_{1000} remains constant. When more yarn is held in the loops the bed separation effect becomes relatively smaller. Thus relatively high settings of KOC and KOD lead to the best condition with D as short as possible.

If rob back is now introduced in the same manner as previously, the new values compared with the settings are as shown in Table 2.5 and Figure 2.11 along with the amount of

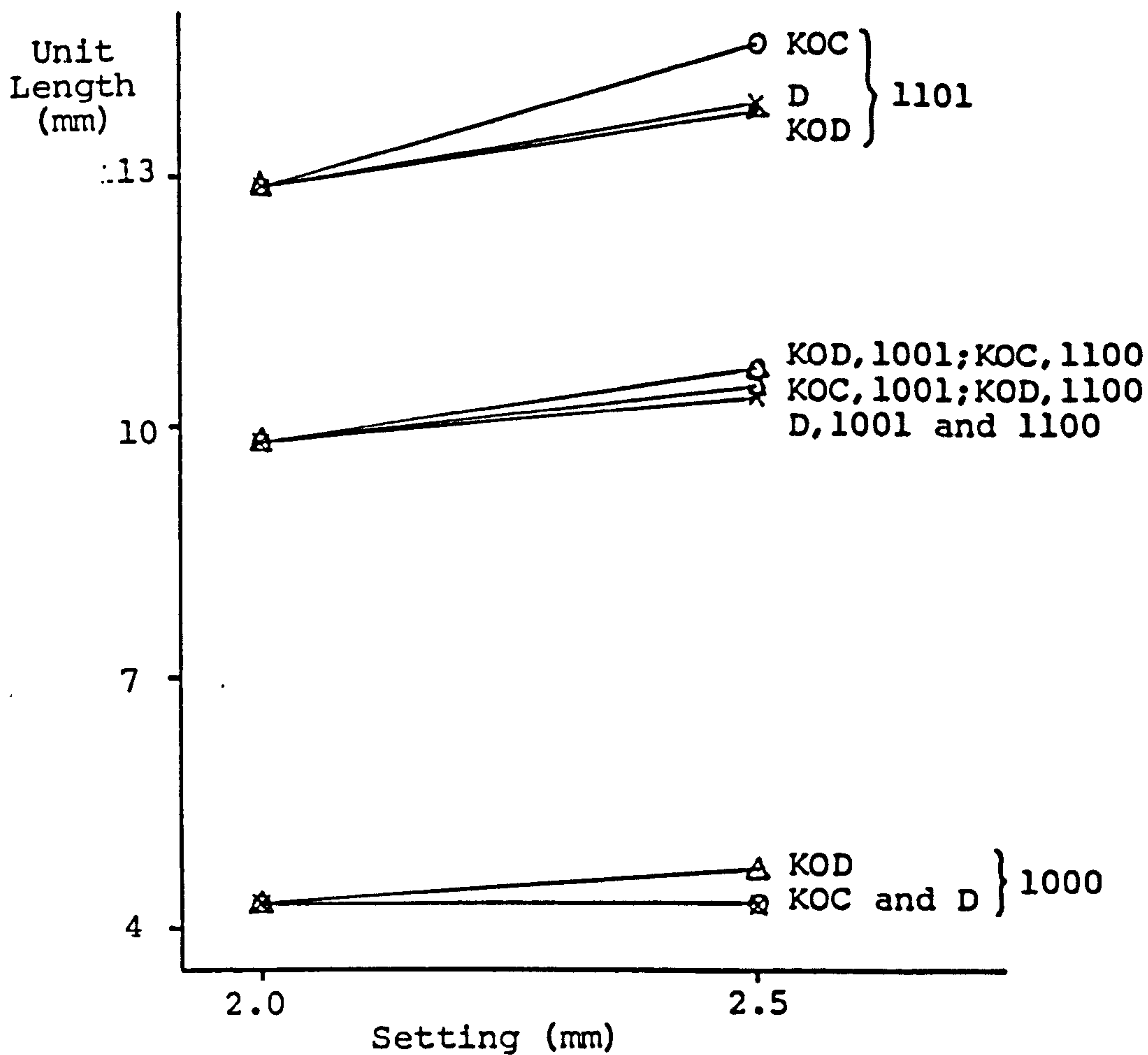


Figure 2.11 Jacquard unit lengths v. settings for 18 gge fabric with half restricted rob back. The three settings, designated by point type, are varied in turn while the remaining two settings are held at 2.0 mm.

Table 2.6

Results for L_{1001} and L_{1100} with different knock over depths on cylinder and dial. Here KOC = 2.5 mm, KOD = 2.0 mm and D = 2.0 mm.

Rob Back Condition	L_{1001} (mm)	%Rob Back	L_{1100} (mm)	%Rob Back
unrestricted	7.97	38	8.68	31
half restricted	10.46	19	10.66	16

yarn robbed back. Both the case of unrestricted and half restricted robbing are considered. For the 1000 unit with unrestricted robbing off one loop it can be seen that in all cases all the yarn on the loop is drawn out again as the needle moves down the cam. This can be avoided when two loop holding needles are on the cam and the knock over depth is greater than 0.28 mm.

The most interesting aspect is seen in the 1001 and 1100 cases when the cam depths are not the same on both beds. This is shown on Table 2.6. Here the resulting yarn lengths are not equal. If this proves to be true in the practical situation, then the machine must be set up with KOC and KOD equal.

Restricting the robbing back to only half the available yarn does not alter the effects on the ratios. The 1000 unit in this case does not have all the yarn robbed from its loop section. Relatively less yarn is robbed from the 1001, 1100 which is in turn less than that for the 1000. This, as found previously in rob back cases, is related to the number of needles on the cam at one time.

The effects of setting changes on the ratios $L_{1001}:L_{1000}$ and $L_{1101}:L_{1000}$ are important guides to the nature of the action within the knitting cycle. Tables 2.4 and 2.5 show the effect on these ratios of changes in each of KOC, KOD and D while the other two variables are held at 2 mm.

Increases in KOD result in fairly rapid reductions in $L_{1001}:L_{1000}$ for both rob back and no rob back conditions. The values of this ratio are higher for the no rob back case. The ratio $L_{1101}:L_{1000}$ also reduces quite rapidly with increases in KOD.

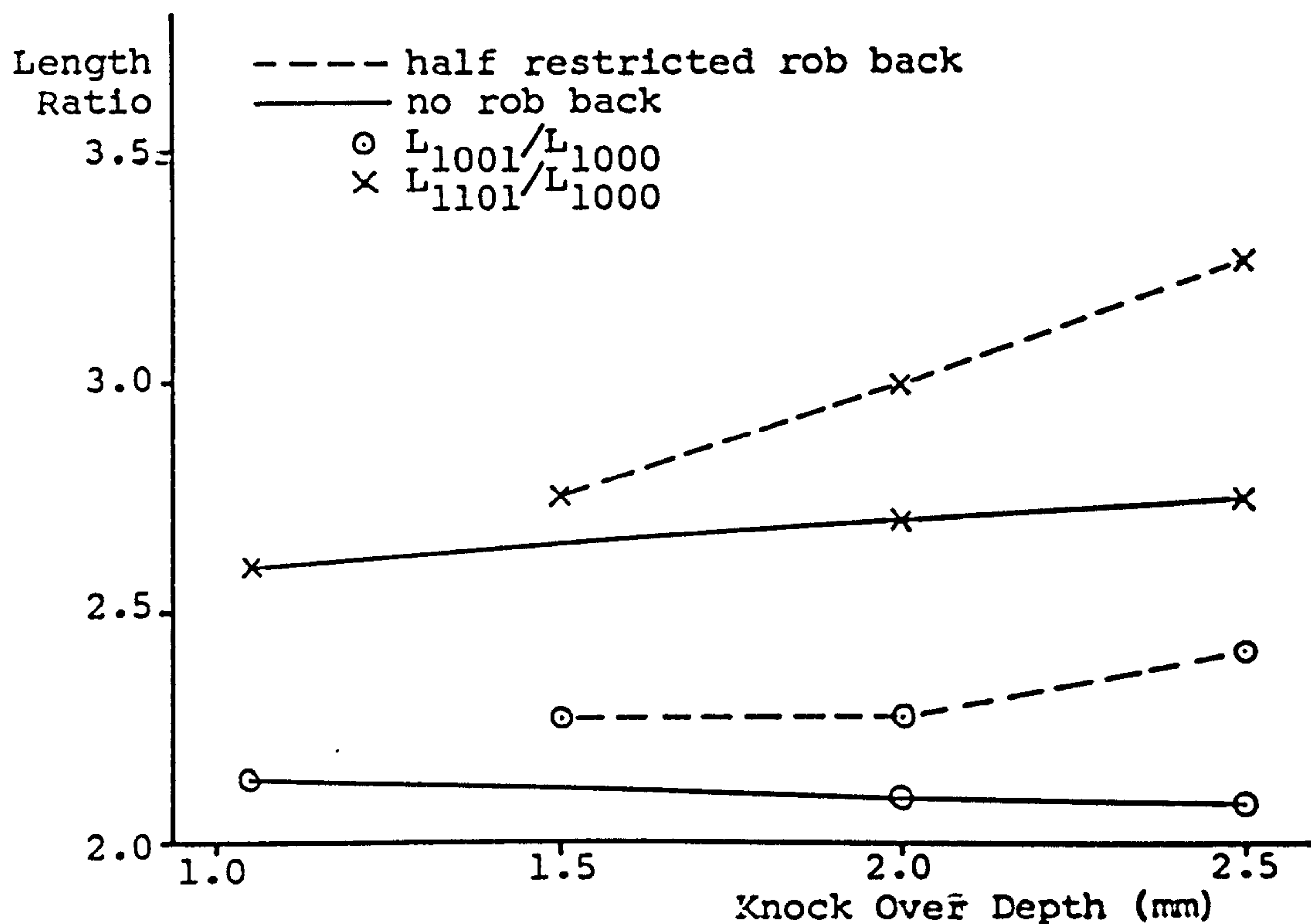


Figure 2.12 Length ratios v. knock over depth with and without rob back. The knock over depth is kept the same on both beds.

Table 2.7

Measured and calculated unit lengths (mm).

Fabric	KOC	KOD	D	L_{1000}	Mean of all L_{1100} & L_{1001}	L_{1101}	L_{1001}	L_{1100}
1	2.0	2.3	1.4	5.07	9.71	11.87	9.74	9.67
2	2.3	2.3	1.4	5.06	9.95	12.88	10.09	10.11
3	2.5	2.3	1.4	5.00	10.53	13.47	10.61	10.68
4	2.7	2.3	1.4	5.04	10.97	14.36	10.93	11.18
no rob back	1.7	1.7	1.4	5.09	-	12.44	9.05	9.05
$\frac{1}{2}$ restricted	2.3	2.3	1.4	4.58	-	13.32	9.58	9.58
25% rob back	2.3	2.3	1.4	5.00	-	12.26	9.24	9.24
20% rob back	2.3	2.3	1.4	5.26	-	13.04	9.90	9.90
$\frac{1}{2}$ restricted	2.0	2.3	1.4	4.58	-	12.67	9.24	8.89
$\frac{1}{2}$ restricted	2.5	2.3	1.4	4.58	-	13.96	9.81	9.92
$\frac{1}{2}$ restricted	2.7	2.3	1.4	4.58	-	15.04	10.15	10.35

Both ratios increase with KOC or D with or without rob back.

When KOC and KOD are changed together the differences between the rob back and no rob back cases emerge. $L_{1001}:L_{1000}$ reduces slowly in the no rob back case while it increases slightly in the rob back case for equivalent changes in the cam depths. $L_{1101}:L_{1000}$ increases fairly slowly for no rob back while it increases quite rapidly when rob back occurs. These changes are shown in Figure 2.12.

2.2.5.2 Comparison with Practical Results

In order to test the validity of the calculated L_{1000} , L_{1100} , L_{1001} and L_{1101} values for two and three colour jacquard fabrics, a comparison with practical results is now undertaken.

2.2.5.2.1 Three Colour Results

For the three colour case results from the fabrics knitted for section 1.3 and shown in Appendix 4 are used. When the practical lengths for fabric 2 (see Table 2.7) are compared with the theoretical no rob back values it is seen that they lie closest to the values calculated for a knock over depth of 1.7 mm on both beds and a bed separation of 1.4 mm. While fabric 2 was knitted with this same bed separation, a larger knock over of 2.3 mm was used. This underestimation of the knock over obtained from the model indicates that some rob back must be taking place. When the practical settings are used in the free rob back calculation the resultant lengths are considerably less than the measured values, indicating that the model allows a greater degree of

robbing back than has actually taken place. For half restricted rob back the calculations give results much closer to the predicted case, though L_{1000} and L_{1100} are underestimated (4.58 and 9.58 compared with 5.06 and 9.95 respectively) and L_{1101} is overestimated (13.32 compared with 12.88). This would seem to indicate that the nature of robbing back is different for the various units. Table 2.7 shows these results as the lengths of individual units along with the machine settings for knock over and needle bed separation.

The calculations can be modified to consider robbing back of a given percentage off each loop within the repeat. If the situation is considered at 25% rob back, L_{1000} is found to closely approximate the practical results but L_{1100} and L_{1101} are underestimated. At 20% rob back, again off the loops only, the model overestimates both L_{1000} and L_{1101} while L_{1100} is about right. Thus the actual robbing is about 25% off the loops in the 1000 unit and 20% off 1100. Rob back of 22% gives the correct result for the 1101 unit. This indicates an important element in knitting of the various units in combination. Results for other settings are also shown on Table 2.7 and similar relationships can be seen.

An important aspect here is the difference between L_{1001} and L_{1100} for the fabrics with asymmetric cam settings. If the 1100 and 1001 units are considered separately there is some indication that they are different under these conditions. This is especially apparent in fabric 4. Of course fabric 2 would be expected to give the same values for each unit. The other samples show changes near to that predicted by the half restricted rob back model.

Another important aspect of the nature of robbing back

Table 2.8

Results from two colour jacquard fabrics¹³⁷.

Cam Setting	Treatment	B_1	B_2	B_3	B_3/B_2	B_1/B_2
25	$T_0D_0P_0$	1.034	0.394	0.816	2.62	2.07
35		1.202	0.442	0.969	2.72	2.19
45		1.394	0.513	1.056	2.72	2.06
25	$T_1D_0P_0$	0.965	0.353	0.776	2.73	2.20
35		1.148	0.411	0.876	2.80	2.13
45		1.317	0.456	0.989	2.89	2.17
25	$T_0D_1P_0$	1.093	0.405	0.868	2.69	2.14
35		1.276	0.468	1.003	2.73	2.14
45		1.461	0.522	1.101	2.79	2.11
25	$T_1D_1P_0$	1.013	0.372	0.779	2.72	2.09
35		1.198	0.426	0.886	2.81	2.07
45		1.367	0.463	1.045	2.95	2.26
25	$T_0D_0P_1$	1.087	0.414	0.819	2.63	1.97
35		1.267	0.461	0.982	2.75	2.13
45		1.432	0.518	1.135	2.76	2.19
25	$T_1D_0P_1$	0.991	0.365	0.764	2.72	2.09
35		1.150	0.413	0.886	2.78	2.15
45		1.326	0.463	1.016	2.86	2.19
25	$T_0D_1P_1$	1.095	0.405	0.883	2.70	2.18
35		1.271	0.464	1.023	2.74	2.20
45		1.454	0.535	1.115	2.72	2.08
25	$T_1D_1P_1$	1.012	0.372	0.773	2.72	2.08
35		1.198	0.424	0.908	2.83	2.14
45		1.375	0.476	1.041	2.89	2.18

Input tension: $T_0 = 5 \text{ g}$, $T_1 = 25 \text{ g}$ Dial height: $D_0 = 1 \text{ mm}$, $D_1 = 1.5 \text{ mm}$ Take-up setting: P_0 to P_1 is a change of one tooth on the ratchet wheel.

Lengths are shown in centimetres.

Cam settings as on RJ/36

is the effect of sequential order of the various units. The 10011100 combination would be expected to produce longer loops than the 10011001 or 11001100 due to the effect of the number of needles simultaneously on the cam. The 10001101 effect is more or less as predicted. The results for the 10011100 combination, which is found on feeds 28, 34 and 36, show a slight increase over the average for the interlock units as expected. The 10001100 shows very little difference from the average of the individual units.

It would seem that robbing back occurs as predicted by the model with rob back half restricted but with some basic variation caused by altered tension conditions between the various units. As discussed in section 1.3.3 the alteration in take-up conditions within the jacquard design will have a large effect on the robbing back conditions. Nevertheless the actual feed demand should lie very close to that predicted by the half restricted rob back model.

2.2.5.2.2 Two Colour Results

Fahmy and Newton¹³⁷ investigated the effect of various settings on the loop units within a two colour jacquard sample. Their results, which will be used to test the model for the two colour jacquard, are presented in Table 2.8. The unit length values were obtained by measuring courses taken from the pattern repeat and using a best fit procedure to reduce these values to the three independent units used in their work. No difference between 1001 and 1100 was considered but as the cam settings were always the same on both dial and cylinder no length difference would be expected between these units.

From the results it can be seen that cam setting is by far the most important of the variables considered. They found that this does not interact with any of the other variables. As the fabrics were produced at two levels of take-up rate (P) for each of the cam settings, the take-up tension would have been less as the loops got bigger and so it is difficult to isolate the cam effects.

It can be seen that the dial height setting affects the 1000 unit (B_2), which decreases in length as the dial height increases. Increasing the dial height will increase the length of all elements crossing the needle beds. Here the lengths of the 1100 (B_3) and 1101 (B_1) units are increased as expected. This increase must alter the rob back conditions, reducing the effective take-up tension on the 1000 units resulting in the reduced length of this unit.

The change in take-up setting, P, seems to have minimal effect on the unit lengths.

Input tension however has a major effect on the unit lengths. It must be remembered that a reduced loop size will effectively increase the take-up tension and hence tend to restrict rob back. Thus input tension has a major effect on the take-up conditions. Here this can be seen by the increase in the ratio $B_3:B_2$ ($L_{1100}:L_{1000}$) which, as discussed previously, is indicative of increased rob back.

For these fabrics it can be seen that $L_{1001}:L_{1000}$ lies in the range 1.97 to 2.20. This has been predicted to be a slow moving variable which tends to increase with cam setting when rob back occurs and reduce slightly with cam setting if there is no rob back. When the bed separation is 2mm and KOC and KOD are changed together with no rob back, this ratio is

Table 2.9

Measured and calculated unit lengths for two colour jacquard fabric. All lengths and settings are in millimetres except the settings for fabrics $T_0D_1P_1$, $T_0D_0P_1$ and $T_1D_1P_1$.

Fabric	D	KOC & KOD	B ₁ or L ₁₁₀₁	B ₂ or L ₁₀₀₀	B ₃ or L ₁₁₀₀
$T_0D_1P_1$		25	10.95	4.05	8.83
		35	12.71	4.64	10.23
		45	14.32	5.18	11.35
no rob back	1.90	1.2	10.34	4.06	8.83
	1.90	1.5	12.11	4.65	9.68
	1.90	1.8	14.21	5.35	10.08
$\frac{1}{2}$ restricted	1.90	1.6	10.64	3.86	8.56
	1.90	2.5	15.33	4.73	11.14
30% rob back	1.90	1.6	10.95	4.05	8.83
	1.90	2.5	13.75	4.76	10.41
$T_0D_0P_1$		25	10.87	4.14	8.19
		35	14.32	5.18	11.35
$\frac{1}{2}$ restricted	1.55	1.6	9.94	3.86	7.88
	1.55	2.5	14.63	4.73	10.47
$T_1D_1P_1$		25	10.12	3.72	7.73
		35	11.98	4.24	9.08
		45	13.75	4.76	10.41

calculated to be about 2.1. When half restricted rob back is introduced, the ratio is about 2.2 to 2.4 over normal cam settings for an 18gge machine. Thus the experimental values of this ratio indicate that rob back is usually occurring but perhaps not to the extent of the half restricted case.

The practical $L_{1101}:L_{1000}$ ratio range is from 2.6 to 2.95. The no rob back model with a bed separation of 2mm gives the range of 2.6 to 2.8, while the half restricted rob back gives 2.6 to 3.3. Here it seems that rob back is occurring at times up to that of the half restricted case.

If bed separation is reduced $L_{1001}:L_{1000}$ would decrease further than $L_{1101}:L_{1000}$ since while both have approximately two bed separation lengths in them the percentage change is greater in the former ratio. L_{1000} would not be expected to alter.

Consider now the actual machine settings. Fahmy and Newton quote the settings on the machine rather than the actual cam depths, and the dial height not the needle bed separation. Hence a certain amount of guess work is required to estimate the parameters to be used in the yarn movement model. Table 2.9 shows the values for the $T_0D_1P_1$ sample along with some estimated settings. This sample is used as a starting point as it is the case with the least rob back since it has the longest unit lengths. The theoretical no rob back results for the settings which give the closest estimates ($KOC=KOD=1.2, D=1.9mm$) are shown. There appears to be a strong tendency to underestimate L_{1101} . All these settings are, however, quite feasible as knitting conditions. If the half restricted values with $KOC=KOD=1.6mm$ and $D=1.9mm$ are used there is a tendency to underestimate L_{1000} and, at the higher

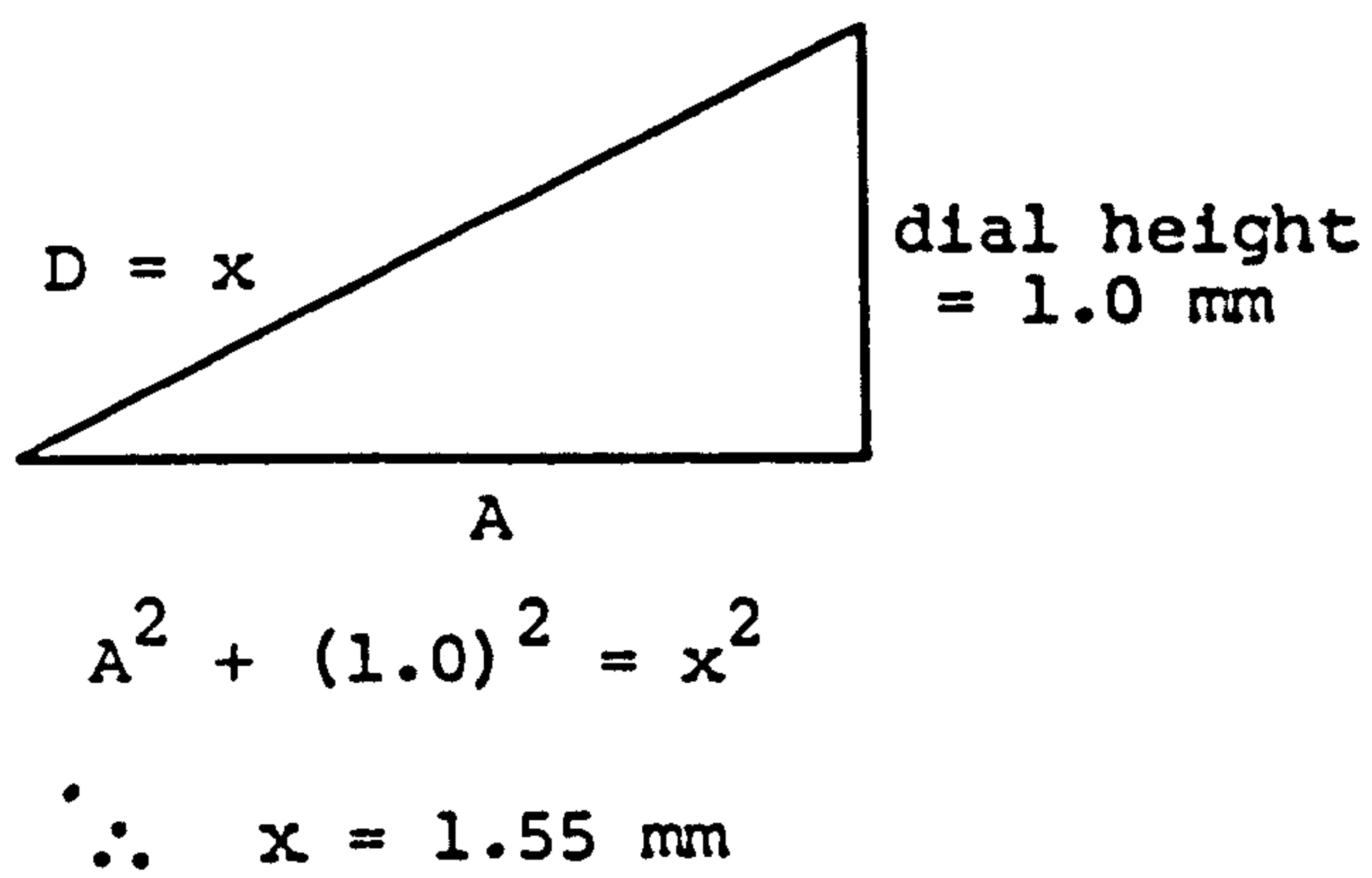
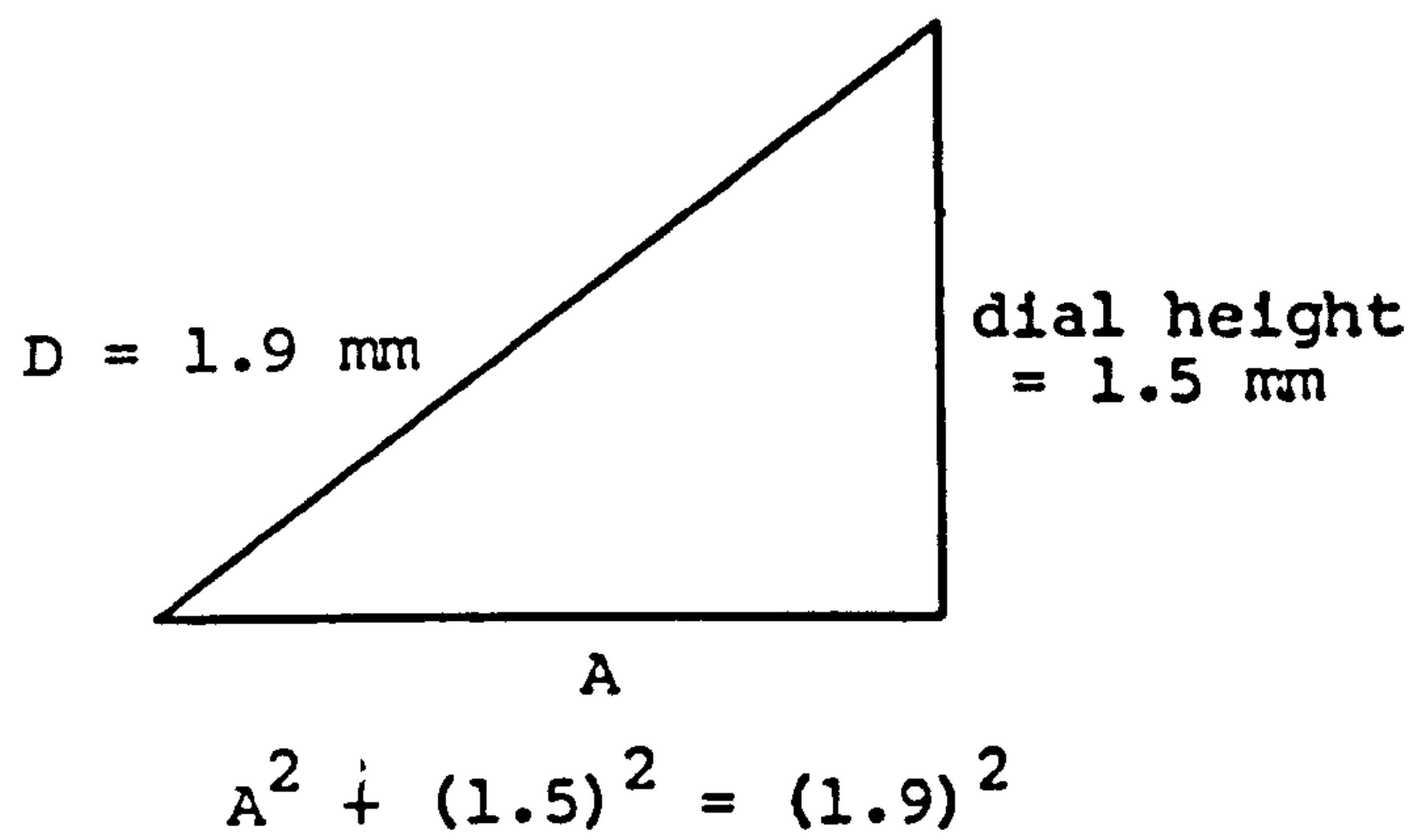


Figure 2.13 Relationship between needle bed separation, D, and dial height.

knock overs, to overestimate L_{1101} and underestimate L_{1001} . Thus while some robbing back is obviously occurring it may not be under the same conditions for each of the units. For the same settings 30% rob back from the loop sections gives a very close fit at the low cam setting but underestimates the lengths at high cam settings.

Fahmy and Newton's dial height of 1.5 mm does however seem to correspond to the bed separation of 1.9 mm. If this is the case then the 1 mm dial height would be expected to correspond to the bed separation of 1.55 mm as shown in Figure 2.13.

The half restricted rob back model with the reduced bed separation underestimates the practical results ($T_0D_0P_1$) at the low value of cam setting while at the highest setting the values are very close. Considering that reduced cell length will effectively increase take-up tension and reduce rob back these results seem to give a very good estimate. Thus for the $T_0D_0P_1$ samples it seems that robbing back, while it may vary slightly between the three units, is of the order estimated by the half restricted rob back yarn movement model.

At the increased input tension of 25 g it seems that the rob back is increased beyond these values. For the same estimated settings as used for $T_0D_1P_1$ the unit length values for $T_1D_1P_1$ are nearly always overestimated by the half restricted rob back model at all cam settings. The one exception is L_{1101} at the lowest cam setting. So here the rob back is taking place from greater than half the available loop. The difference is greatest for the high unit values as would be expected from the effective reduction in take-up tension. The model at 30% rob back predicts exactly the

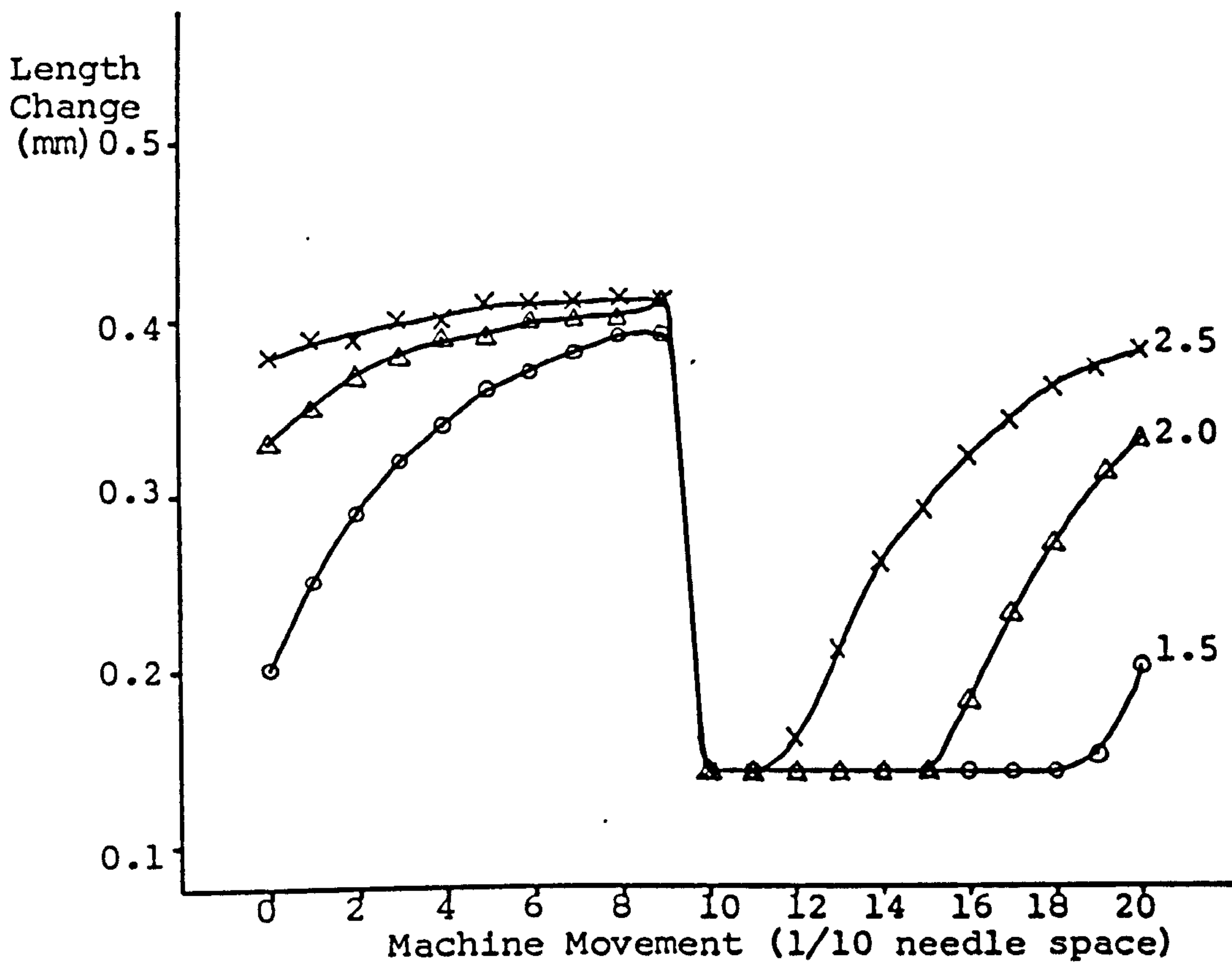


Figure 2.14 Yarn length change in the 1000 unit v. needle movement for the 18gge no rob back case. The knock over depth, in millimetres, is shown at the end of each curve.

results at the highest cam setting but overestimates at the low cam settings.

The higher input tension of 25 g would rarely be encountered in the practical knitting situation. Thus the half restricted rob back model can be considered to give a useful estimation of the unit lengths for the common two colour jacquard case.

2.2.5.3 Yarn Movement for Jacquard Units

The length groups predicted by the yarn movement model have been seen to compare favourably with those actually measured in the two and three colour jacquard fabrics considered. The closest results were obtained using the half restricted rob back condition. This, along with the no rob back condition, will be used to predict the way in which yarn is drawn into the jacquard units.

2.2.5.3.1 The 1000 Unit

The program already discussed (see Appendix 6) was used with the no rob back conditions, to examine the effect of various knock over settings for the shortest of the jacquard units (1000). The results are shown in Figure 2.14 and Appendix 9. It can be seen that the basic shape of the curves on Figure 2.14 consists of two vastly different sections: one where the needle is drawing yarn into the structure and the other where the needle that is not knitting passes through the feed zone. The latter is seen as a flat section at 0.14mm, corresponding to the machine rotation. Because only every second dial needle is used here only one needle takes on yarn at a time. Increasing the knock over depth reduces the distance

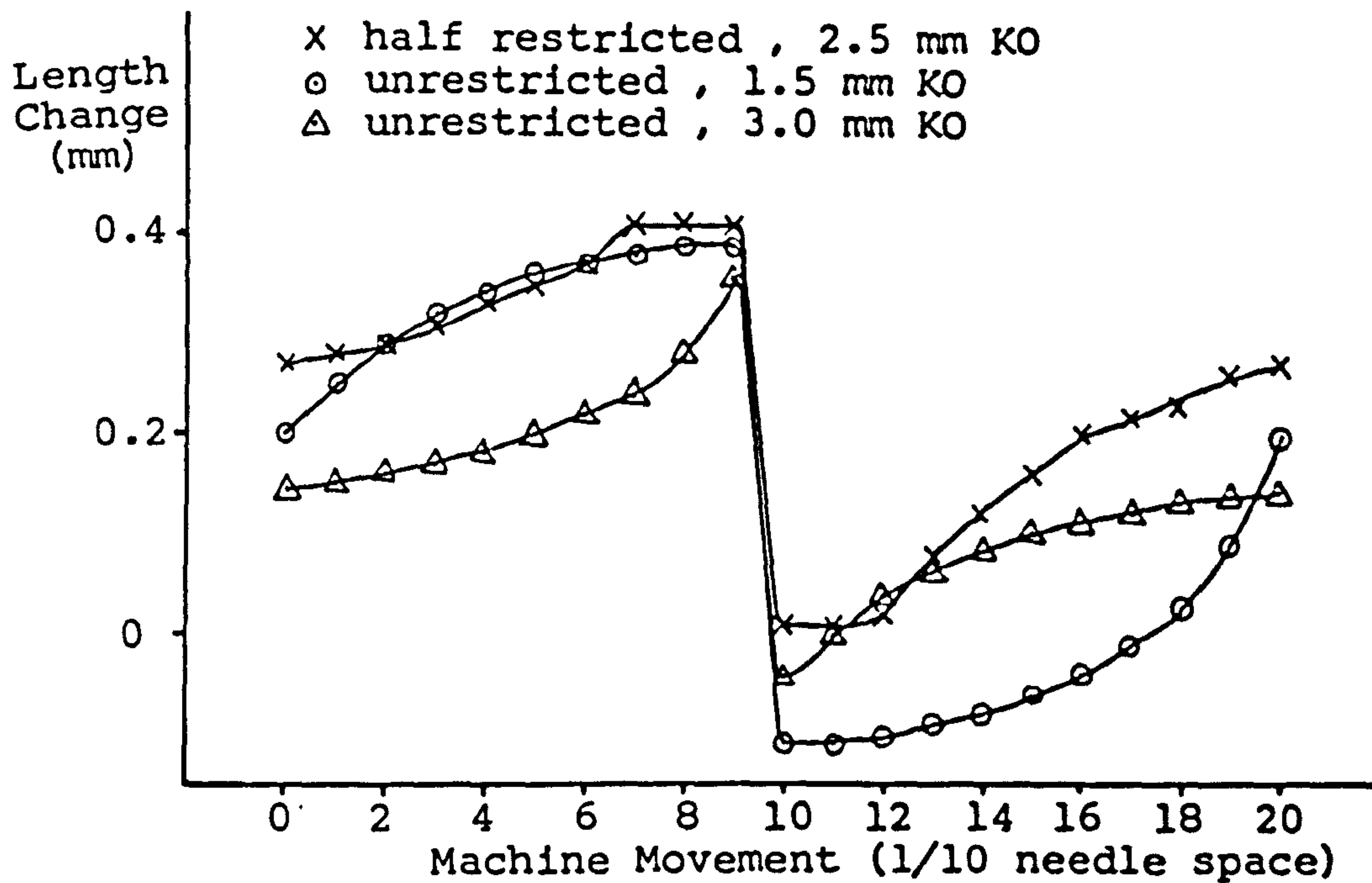


Figure 2.15 Yarn length change v. machine movement for the 1000 unit. The rob back condition and knock over depth is shown by point type for an 18 gge machine.

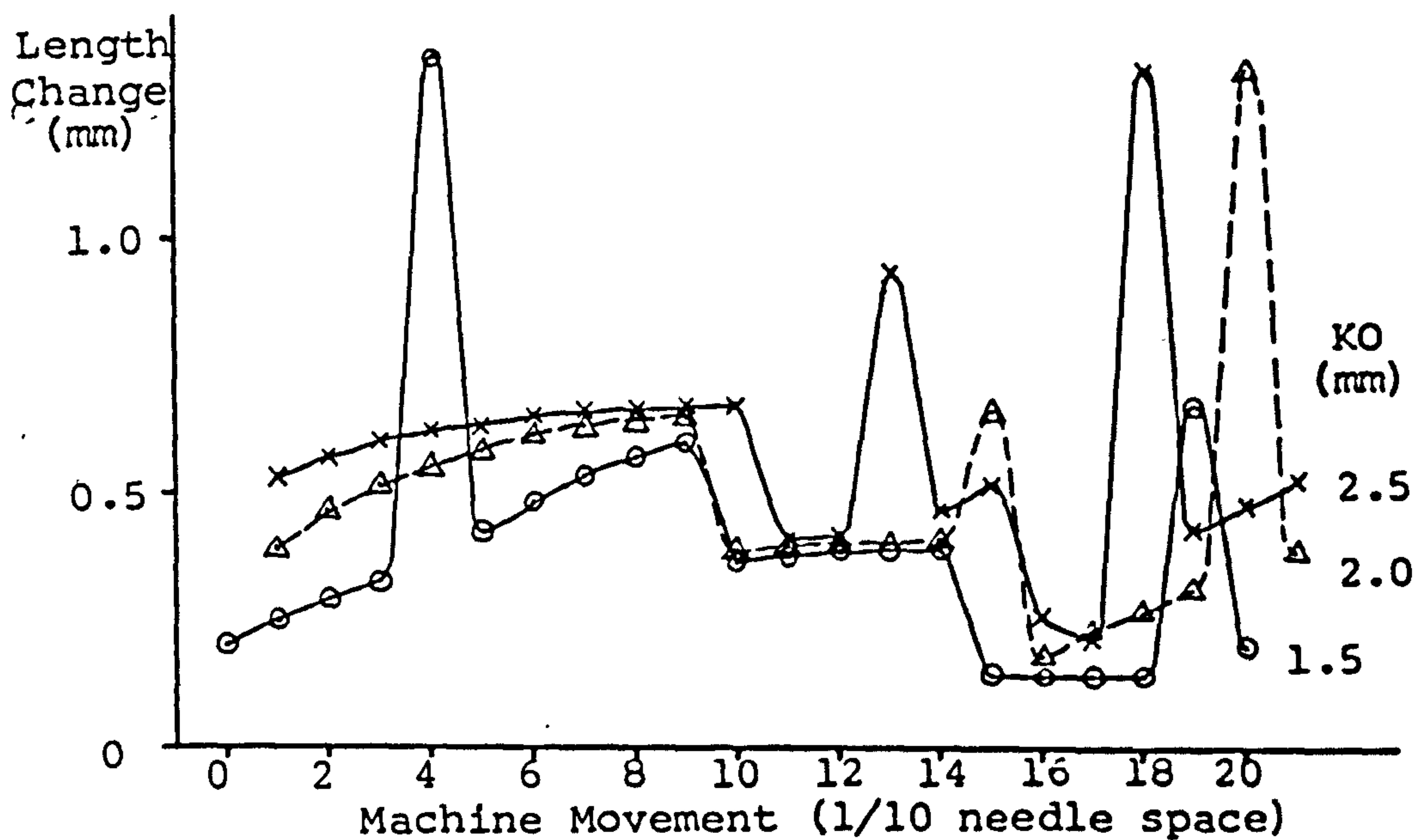


Figure 2.16 Yarn length change v. machine movement for the 1001 unit on an 18 gge machine with a 1 mm bed separation and no rob back. The knock over depths are the same on both beds.

between needles on the cam. When the setting equals two needle spaces the flat section on the curve disappears.

With unrestricted robbing back off one loop, as shown in Figure 2.15 and Appendix 9, all the yarn from the loop held on the needle leaving the knitting zone is drawn onto the single knitting needle on the cam resulting in only the straight line length of 2.8 mm being fed. This could not actually occur in practice but serves to show how rob back increases the variation within the cycle. Using the half restricted rob back condition shown on Figure 2.15 for the 2.5 mm knock over case, the length demand variation is increased over the no rob back case but maintains the same basic form. The half restricted rob back at a knock over of 2.5 mm and the no rob at a 1.5 mm knock over give the same total length fed, with the former case showing a greater range of feed speed requirements.

2.2.5.3.2 The 1001 and 1100 Units

The knitting of the 1001 and 1100 units involves a combination of loop forming with cross overs from one needle bed to the other. The feed demand is similar to 1x1 rib in that rapid cross overs between the beds alternate with the drawing of yarn into the loops. All results for these units are shown in Appendix 10. For the case without rob back (see Figure 2.16) the 1001 and 1100 units act as mirror images and so only 1001 is presented. Here the two cross over peaks dominate with one much greater than the other. The size of these peaks is determined by the needle bed separation (1 mm in the cases presented). The effect of the number of needles on the cam can be clearly seen. On the 1.5 mm

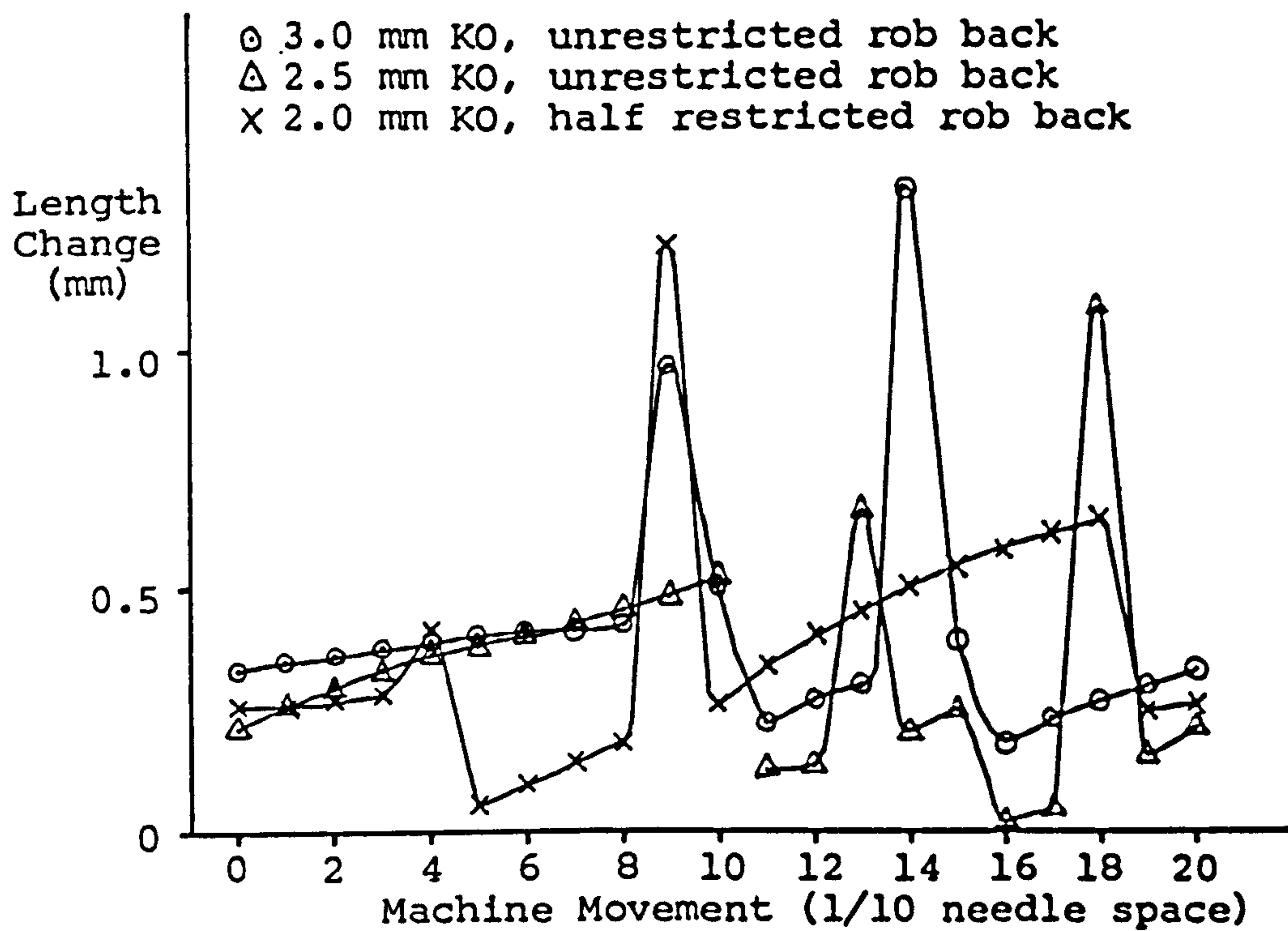


Figure 2.17 Length change v. machine movement for the 1001 unit with rob back. The machine is 18 gge, $D = 1$ mm and $KOC = KOD = KO$.

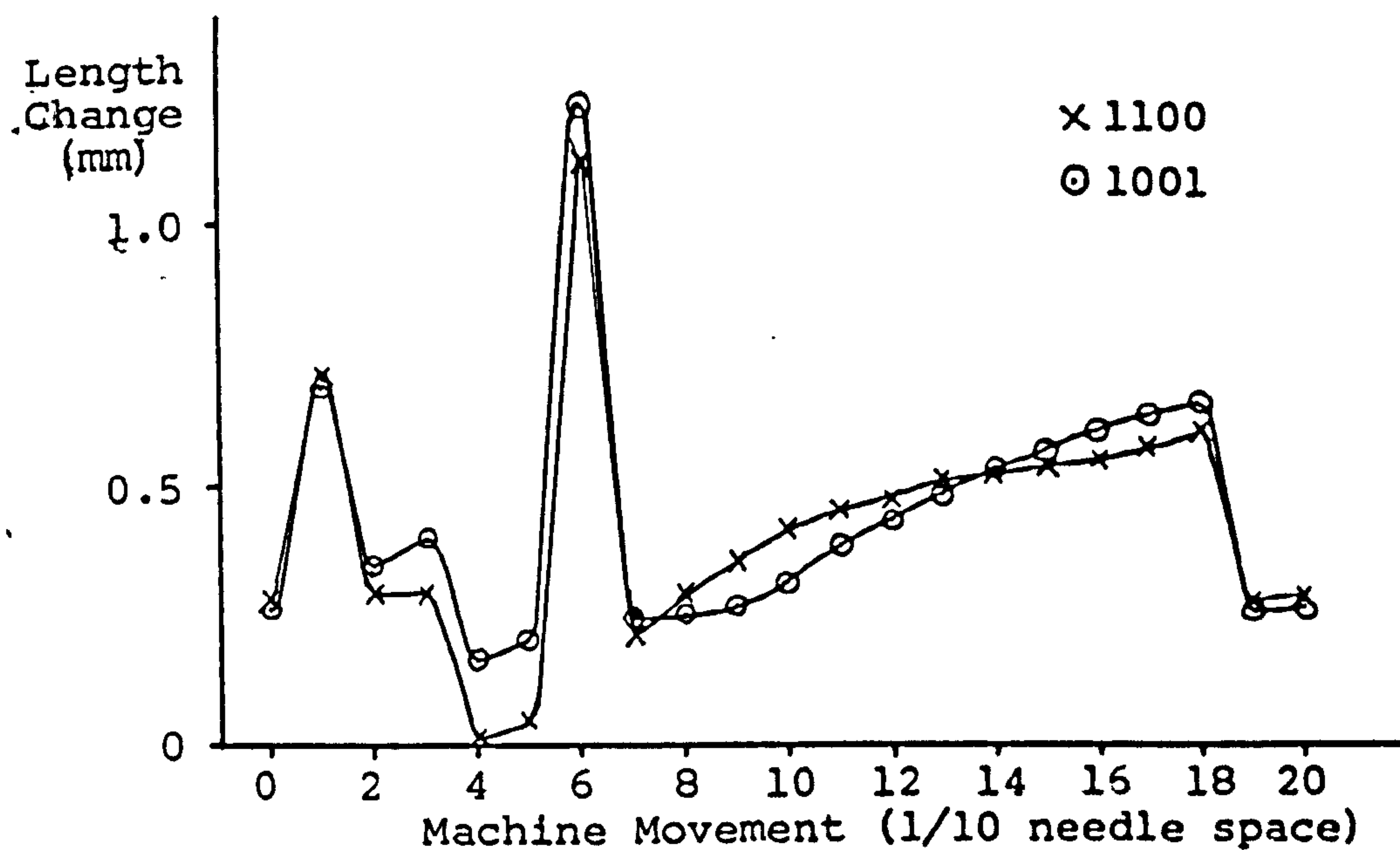


Figure 2.18 Length change v. machine movement for the 1100 and 1001 units with half restricted rob back where $KOC = 2.0$ mm, $KOD = 2.5$ mm and $D = 1.0$ mm at 18 gge.

knock over curve there is a section with no needles on the cam (a feed of .14 mm per one tenth needle space which is machine rotation only), one needle on the cam and two needles on the cam. As the knock over depth is increased to 2.0 mm the section with no needles on the cam disappears and the two needle section becomes larger. At the 2.5 mm knock over a section with three needles on the cam is introduced. The variation within the cycle is from 0.14 to 1.35 mm for the 1.5 mm knock over depth and 0.18 to 1.34 mm for the 2 mm depth.

Curves are also shown in Figure 2.17 for the case when robbing back occurs freely off one needle. Here a similar repeat length to that of the 1.5 mm knock over with no rob back is achieved with a knock over of 3.0 mm. The variation within the cycle is between 0.1 and 1.09 mm which gives a slight improvement over the case with no rob back. Thus here, unlike in the 1000 case, allowing rob back reduces the variation within the cycle.

Also shown on Figure 2.17 is the half restricted rob back case with a knock over of 2.0 mm which gives a similar repeat length to the no rob back at 1.5 mm knock over. Here the variation is between 0.06 and 1.22 mm which is very close to the no rob back case. The smaller of the cross over peaks is considerably reduced.

An important aspect of the effect of robbing back occurs when the knock over depths are different on the two needle beds. This is demonstrated on Figure 2.18 for the case where KOC equals 2.0 mm and KOD equals 2.5 mm with a bed separation of 1.0 mm. Here L_{1001} is 1.066 mm and L_{1100} is 1.046 mm. In the section of the curve from 1/10 to 6/10

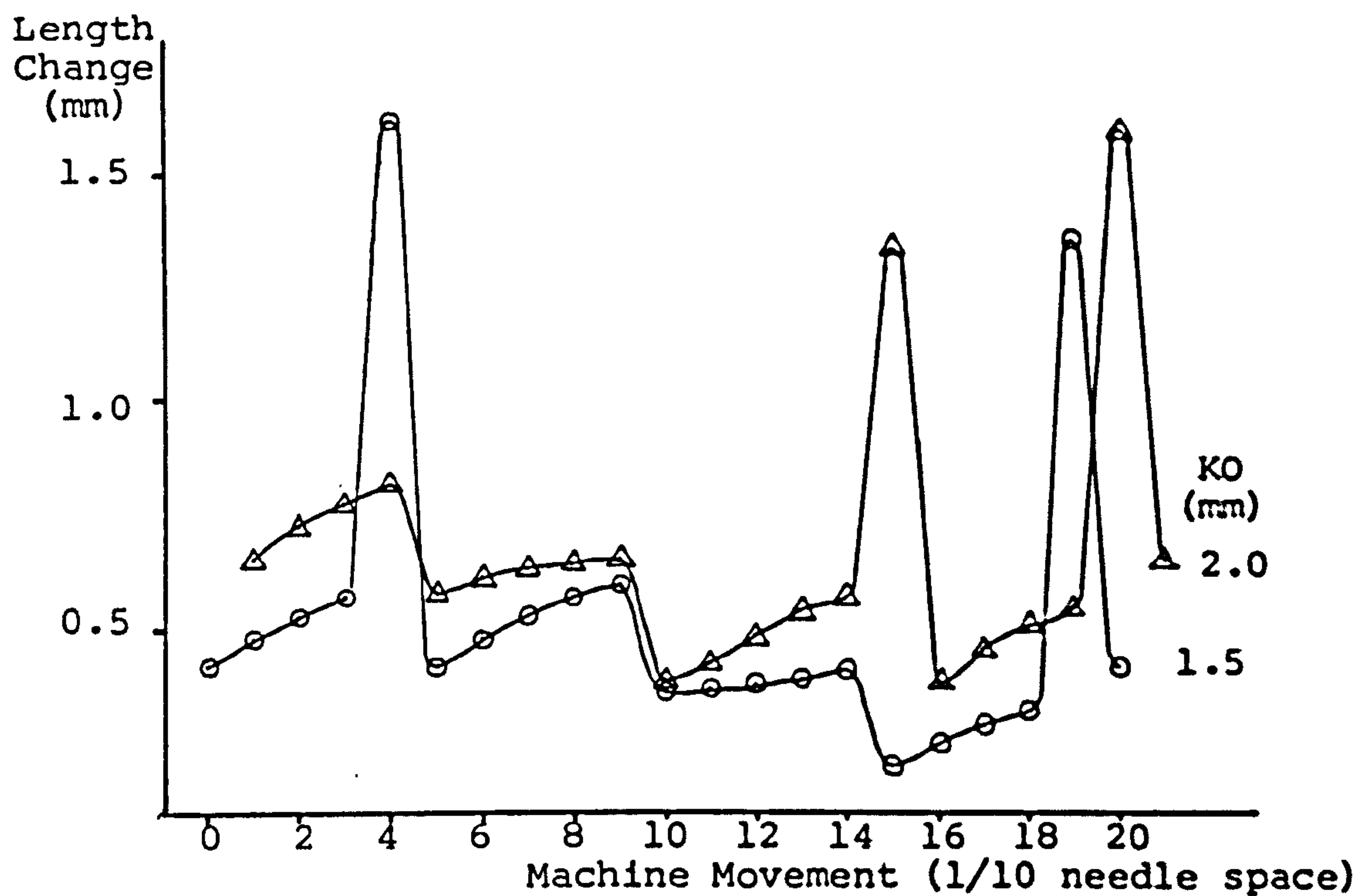


Figure 2.19 Yarn length change in the 1101 unit v. machine movement for the no rob back case on an 18 gge machine with $D=1.0\text{mm}$ and $KO=KOC=KOD$.

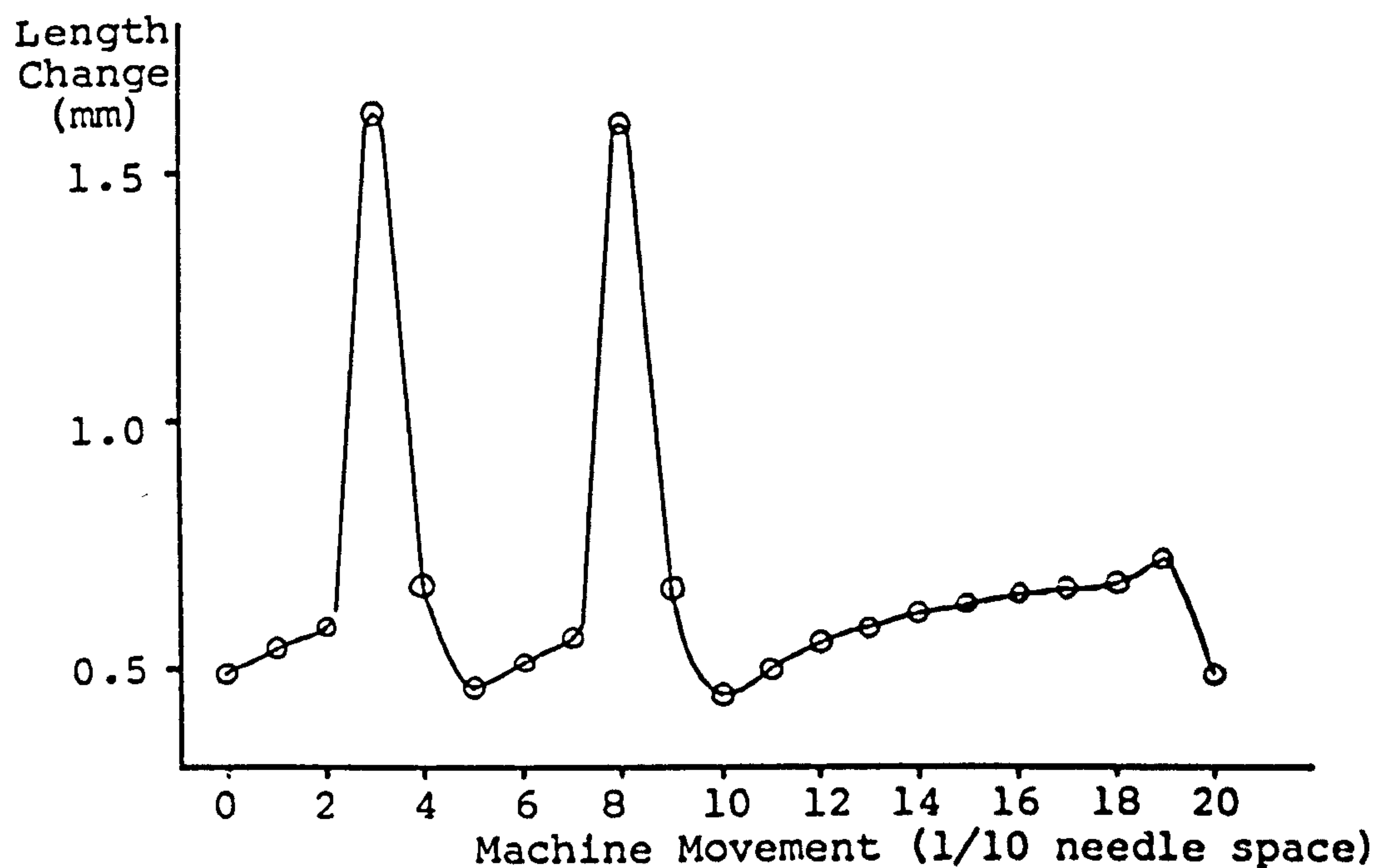


Figure 2.20 Yarn length change in the 1101 unit v. machine movement for the unrestricted rob back case on an 18 gge machine. $D = 1.0\text{ mm}$ and $KOC = KOD = 3.0\text{ mm}$.

needle space yarn is robbed from the dial needle in the case of 1100 and from the cylinder needle in the case of the 1001 and here more yarn is available off the dial needle resulting in the shorter L_{1100} . This is a situation which must definitely be avoided when running jacquard fabric by setting the dial and cylinder cams at the same depth. This of course is only achieved with a loss in flexibility within the ratios used.

2.2.5.3.3 The 1101 Unit

The results for the 1101 unit are shown in Figure 2.19 and Appendix 11 for various settings. Again the two cross overs dominate the curve. This time however they are both of the same form and so are generally of the same height. As in all cases where many needles are involved within the cycle the variation in demand of the loop forming elements is small.

The unrestricted robbing back case is shown on Figure 2.20 for a knock over setting of 3.0 mm which corresponds in repeat length to the 2.0 mm knock over without rob back or the 2.3 mm with half restricted rob back. These three cases have repeat lengths of 1.331, 1.336 and 1.252 mm respectively. A very similar pattern of variation within the cycle is apparent for all these cases.

2.2.5.3.4 Combined Units

Previously only repeated units of the same type have been considered. Without rob back successive units will have no influence on those previously formed. However when rob back occurs the amount of yarn available for robbing and hence the previously knitted loop will influence the yarn movement. This has already been seen within units in section

Table 2.10

Comparison of combined unit lengths with the sums of individual unit lengths as calculated from the yarn movement model with the unrestricted rob back condition. All lengths are in millimetres.

KOC	KOD	D	Combined Unit	Combined Unit Length	Individual Unit Lengths Sum
2.0	2.0	2.0	10001101	13.31	13.14
2.5	2.0	2.0	10001101	14.79	14.01
2.0	2.0	2.0	10011100	15.54	15.54
2.5	2.0	2.0	10011100	16.51	16.65

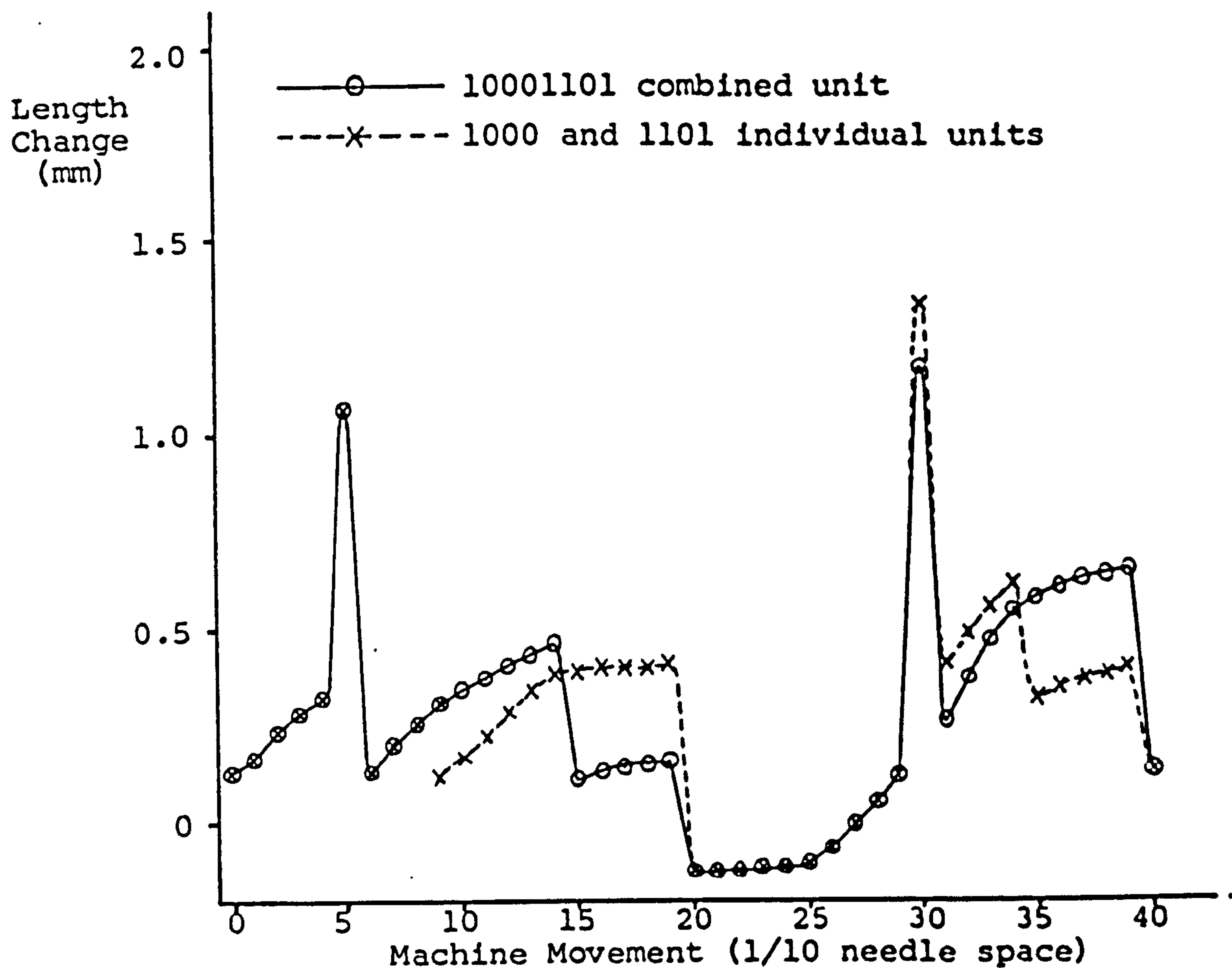


Figure 2.21 Yarn length change v. machine movement for the combined 10001101 unit compared with the individual 1000 and 1101 units plotted in succession. Results shown are for the unrestricted rob back condition with KOC = KOD = 2.0 mm and D = 1.0 mm on an 18 gge machine.

2.2.5.3.2 for the 1001, 1100 case with different knock over depths on the two beds. Table 2.10 shows the difference between the combined unit length $L_{10001101}$ and the sum of the individual unit lengths L_{1000} and L_{1101} for two levels of KOC. Here it can be seen that $L_{10001101}$ is the longer in both cases with the difference being greater for the higher cylinder knock over depth. In the combined unit when the long dial only section with the straight line crosslink (10001) is knitted, most of the yarn is drawn from the previously knitting needle and hence robbing back is limited. Thus more yarn is drawn from the feed. This of course becomes more apparent when the loop on the cylinder is longer. If the demand curves on Figure 2.21 are compared the difference in where yarn is fed can be seen clearly.

For 10011100 the difference between the combined unit length and the sum of the individual unit lengths is much smaller. For the $KOC=KOD=D=2.0$ mm case there is no difference at all (see Table 2.10). When the knock over depth on the cylinder is increased to 2.5 mm however the combined unit is slightly shorter. This was observed in practise as shown in Table 1.6 facing page 40. Again this is due to the effect of the amount of available yarn on the previous needle.

These effects are small however and would generally not be expected to greatly upset knitting.

2.2.6 Feed Types and Their Relationship with the Various Units

The various types of yarn feed have been discussed in section 1.2.1. The manner in which feed demand variations to the different units are influenced by the feed type is now examined.

2.2.6.1 Negative Feeds

For jacquard fabrics by far the most common type of feed is directly off a cone via some type of tensioner. The simple case through a cymbals tensioner is considered here. As shown in section 1.2.1 tension off the cone is dependent upon yarn speed. Curves presented previously in section 2.2 have shown the yarn demand within one cycle as the change required per tenth needle space of machine movement. An 18 gge circular machine with 2000 needles runs at around 16 rpm, which gives a movement of a tenth of a needle space in approximately 0.5 ms. This information can be used to convert the demand variation into yarn speed changes and hence tension variation through the cycle.

For the single knit at a knock over of 2.5 mm a demand variation of 0.33 to 0.57 mm per 0.5 ms or 68.4 to 39.6 m/min is found. This gives a variation in tension from approximately 3.8 to 3.4 g. Using the same settings for 1x1 rib fabric the demand length variation is from 0.8 to 1.8 mm per 0.5 ms which gives a speed variation from 96 to 220 m/min and tension ranging from 4 to 5 g within the cycle. If the knitting machine was running at twice the speed the tension would increase to the range 3.9 to 4.5 g for single knit and 4.2 to 7.5 for 1x1 rib.

The above calculations refer to the tension variations off the cone. To get from the cone to the knitting point on the machine the yarn has to pass various guides. A typical arrangement gives about 180° of wrap. Using Amonton's Law of Friction around a capstan an input tension at the knitting point can be calculated from the above results. For a coefficient of friction of 0.2 a tension range of 5.6 to 7.6 g

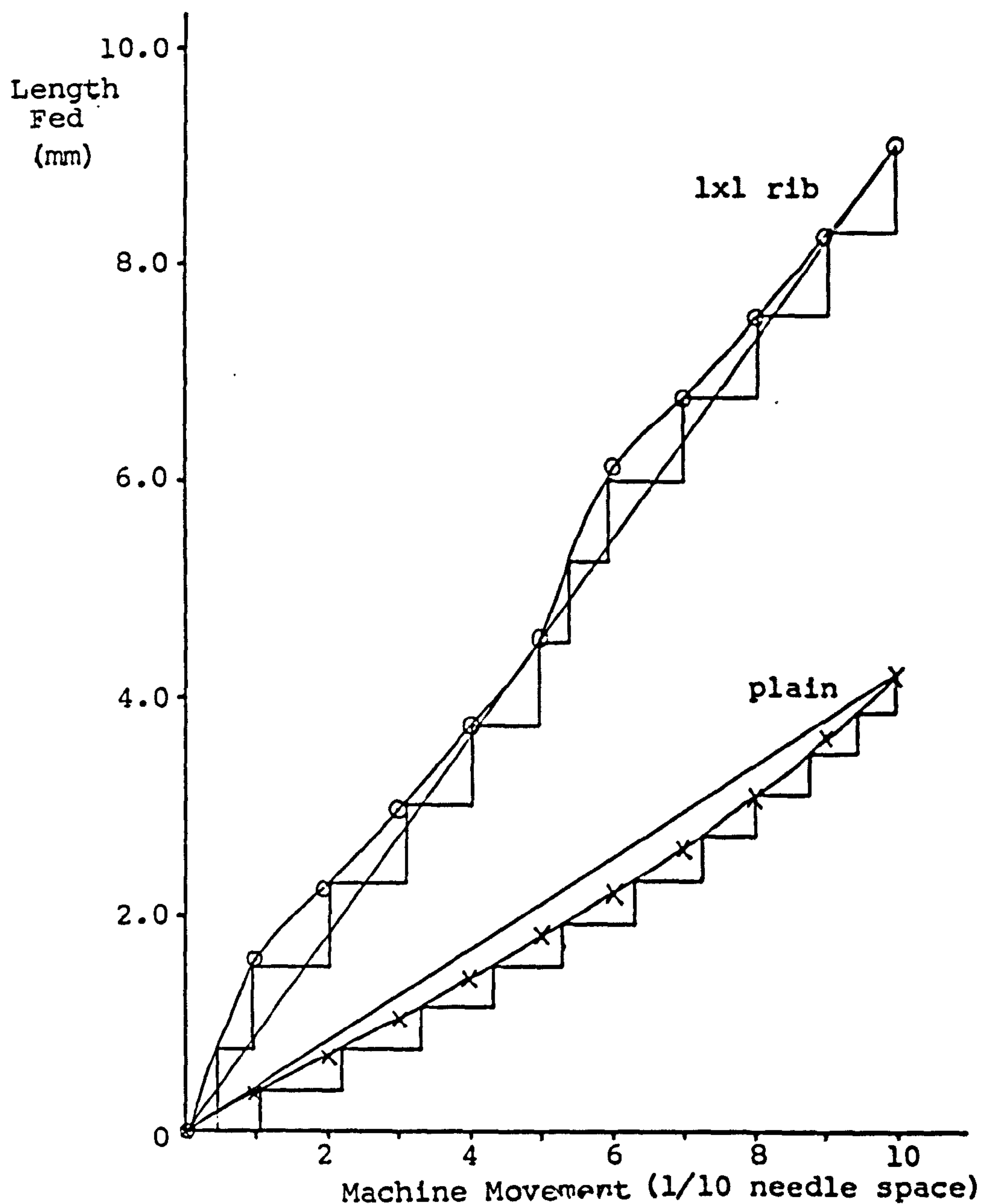


Figure 2.22 Yarn length fed V.machine movement for plain and 1x1 rib fabric knitted at 18 gge with a knock over depth of 2.0 mm and a bed separation of 1.0 mm. The curves with marked points show the actual.length demand, the straight lines are the length fed by a constant speed feed system and the step feed is also shown with 11 steps for plain and 12 steps for 1x1 rib.

Table 2.11

Yarn speed variations and resulting tension changes for the no rob back model with KOC = KOD = 2.0 mm and D = 1.0 mm based on the cymbals 1 results shown in Figure 1.2.

Unit	Min.speed (m/min)	Max.speed (m/min)	Min.tension (g)	Max.tension (g)
1000	17	49	4.4	4.9
1100	22	159	4.5	6.0
1101	48	191	4.9	6.5
plain	40	61	4.8	5.1
1x1 rib	78	191	5.2	6.6

Table 2.12

Predicted tension variations for the constant speed positive feed.

Unit	Max.length variation (mm)	Required extension (%)	Increase in yarn tension (g)	
			1/30s acrylic	150den polyester
1000	0.9	0.09	2.4	1.6
1100	1.3	0.13	3.2	2.4
1101	1.2	0.12	3.0	2.0
plain	0.4	0.04	1.2	0.8
1x1 rib	0.8	0.08	1.8	1.2

is obtained for plain fabric and 7.4 to 9.4 g for 1x1 rib.

The variations in yarn speed and tension can similarly be calculated for the various jacquard units. Results for the KOC=KOD=2.0 mm, D=1.0 mm setting with no rob back are shown on Table 2.11.

For feed through an IRO or similar storage unit the tension at the feed point will remain constant for changes in speed.

2.2.6.2 Positive Feeds

Positive feeds allow the amount of yarn within the structure to be controlled. Only constant speed positive units are available at the moment and, as explained in section 1.2.1, these can only feed to an average demand. The difference between the actual demand and the amount of yarn fed by a constant speed unit is shown on Figure 2.22 for a plain and a 1x1 rib fabric. It has been assumed that the knitting and feed unit have been set up to give the total amount of yarn fed per cycle equal to the total length demanded at the knitting point. The short term differences between supply and demand cause tension variations which must be accommodated by yarn extension.

The general form of demand and hence the resulting tension curve for the plain fabric is a single peak for a single needle passing the feed point. The maximum variation over the supply is about 0.4 mm. If the length of yarn from the feed point to the knitting point is considered to be 1 m an extension of 0.04% would be required. For a 1/30s (29.4 Tex) acrylic yarn at 5 g input tension this would result in a 1.2 g increase in tension. (Stress-strain behaviour of some typical

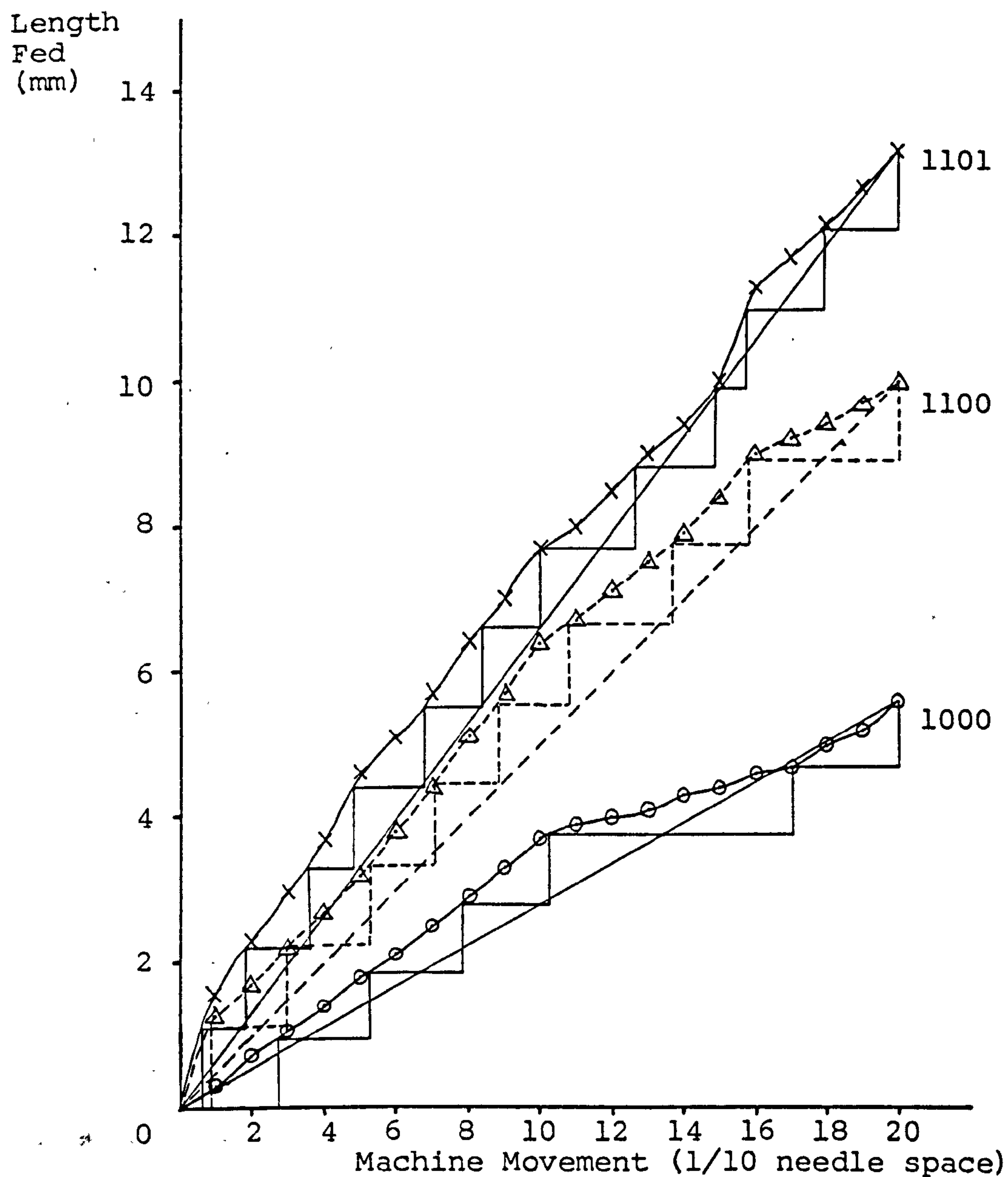


Figure 2.23 Yarn length fed v. machine movement for the jacquard units knitted at 18 gge with a knock over depth of 2.0 mm on both beds and a bed separation of 1.0 mm. The curves with marked points show the actual length demand, the straight lines are the length fed by a constant speed positive feed system and a stepped feed is also shown with 6 steps for the 1000 unit, 9 steps for the 1100 unit and 12 steps for the 1101 unit.

knitting yarns is given in Appendix 2.) For 150 den textured polyester the increase would only be 0.8 g. This is meant as an illustration only, since the actual tension change is dependent on the distance between the feed point and the beginning of the knitting zone, the yarn type and the size of the loop drawn.

In the 1x1 rib case the feed variation within the cycle is greater due to the cross overs between the needle beds. In Figure 2.22 the bed separation is 1 mm. The basic cycle per two needle repeat has two tension peaks. The length demand difference rises here to 0.8 mm or about twice that of the single knit case. Results showing required yarn extension and tension change are shown in Table 2.12. Here it is again assumed that the feed length is the same as that totally demanded in the repeat.

For the jacquard units the difference between supply and demand is shown on Figure 2.23 (for $KOC=KOD=2.0$ mm, $D=1.0$ mm). The 1000 curve has a single peak corresponding to a variation of 0.9 mm within the cycle. Here the effect on the yarn demand of knitting plain on half gauge can be seen clearly. A larger variation compared to the single knit leads to a greater tension variation to maintain control. The 1001 unit fares worse than the 1x1 rib with a variation of 1.3 mm. This variation is between where no needles are drawing yarn and where both needles are on the cam with the cross over occurring. The 1101 unit gives a variation of 1.2 mm, which is again greater than that for 1x1 rib, though not quite as high as for 1001. The results for all the above cases are presented in Table 2.12.

Of course feed related variation will depend upon the

Table 2.13

Step lengths required to improve variation over the constant speed positive feed.

Unit	Repeat Length (mm)	Constant Feed Variation (mm)	Number of Steps	Step Length (mm)
plain	4.24	0.4	11	0.39
1x1 rib	9.10	0.8	12	0.76
1000	5.60	0.95	6	0.93
1100	10.00	1.3	9	1.10
1101	13.22	1.2	12	1.10

Table 2.14

Step presentation times expressed in units of the time taken for the machine to rotate through 1/10 needle space.

Unit	Step												Max Rate (step /s)	Min Rate (step /s)
	1	2	3	4	5	6	7	8	9	10	11	12		
plain	1.1	1.1	1.1	0.9	0.9	1.2	0.9	0.7	0.9	0.6	0.6		5500	2800
1x1 rib	0.5	0.5	1.0	1.0	1.2	0.9	0.9	0.5	0.5	1.0	1.0	1.2	6800	2800
1000	1.7	2.4	2.5	2.4	6.5	4.5							2000	500
1100	0.8	2.4	1.8	2.1	1.6	1.9	2.9	1.1	4.4				4000	800
1101	0.7	1.1	1.6	1.6	1.8	1.8	1.7	2.7	2.2	0.8	2.2	2.0	5000	1200

machine settings since the demand variations within the cycle do. However the variations calculated here seem to be extremely high. For the usual case with a 5 g input there are tension fluctuations up to 3 g which is a 60% change. The variation should be reduced by a means giving a reduction in maximum tension while still maintaining the same minimum tension for yarn control.

Instead of a continuous feed consider a feed of equal length steps. The maximum error or variation could be equal to the step length. Thus if there was only one step per repeat a length variation of the total feed length would result. As the length of the step is reduced the variation will also reduce, reaching a limit of zero for an infinite number of steps per repeat. The length variations can be compared to those calculated previously for the constant speed feed. The minimum number of steps required to reduce the variation below that of the constant speed feed is shown in Table 2.13 giving the step length required in each case.

Here it can be seen that while twelve steps are required to improve the 1x1 rib and 1101 unit cases, eleven are required for plain, nine for 1001 and only six for 1000.

The introduction of these steps to maintain the minimum variation from the demand curve is shown in Figure 2.22 for plain and rib and in Figure 2.23 for the jacquard units. Here it can be seen that the individual positions of each step are not regular within the cycle. The actual time for each step is shown in Table 2.14 along with the maximum and minimum step rates assuming a one tenth needle space movement takes 0.3 ms. It can be seen that fluctuations within the cycle are quite large and extremely high stepping rates are required

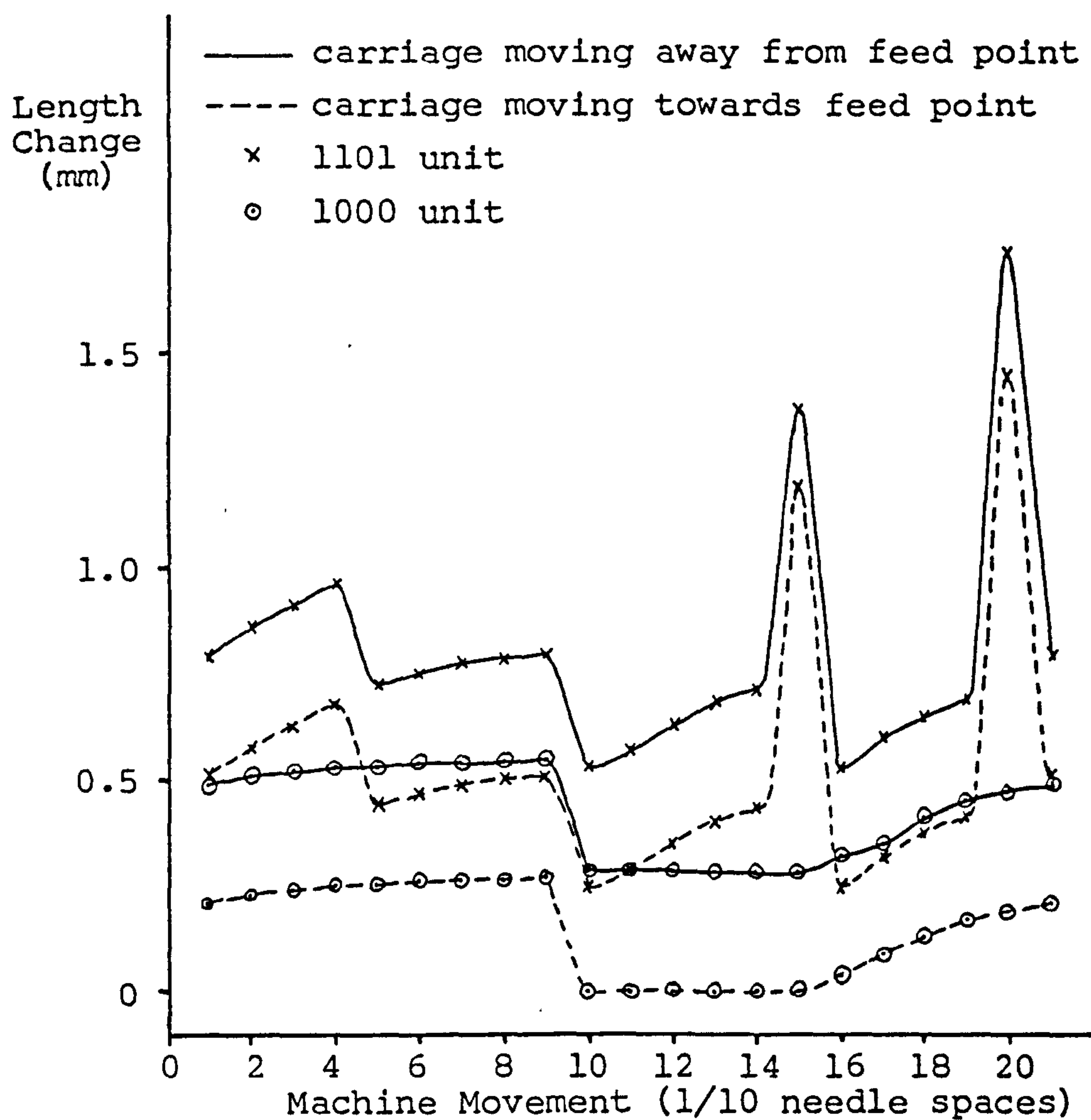


Figure 2.24 Yarn length change v. machine movement for the 1101 and 1000 jacquard units with no rob back knitted on an 18 gge flat bed machine with KOC = KOD = 2.0 mm and D = 1.0 mm.

especially for 1x1 rib.

If the yarn can be stepped in at these rates it should be possible to vary the number of steps between the jacquard units using the same step size. A step feed could then cater for the varying demand within the jacquard structure as a whole.

2.2.7 Modifications for Flat Bed Machinery

The computer program presented in Appendix 6 and discussed in section 2.2.2 carries out the analysis with the effects of machine rotation added in as a separate term independent of the loop forming and cross over elements. To modify this program to predict movement for the flat bed machine feed requires that this section be manipulated. When the cam carriage is moving away from the feed side of the machine the distance it moves must be added to the circular case and when moving in the opposite direction this amount must be subtracted. Thus when the cam carriage moves away from the feed side twice the movement distance is added in, while no addition is made when moving towards the feed. Hence the demand from the cone or a feed located at the side of the machine will be given.

The results for the jacquard units are shown in Figure 2.24 for both directions of carriage movement and given in Appendix 13. These results are for an 18 gge machine with a knock over depth of 2.0 mm on both beds and a needle bed separation of 1.0 mm.

The most important aspect shown here is that the half gauge plain (1000) will require no yarn to be fed for a section of its cycle. This of course necessitates that

a high minimum tension be maintained on the yarn to keep it under control. The variations within the cycle will have the same range as in the circular case but will be different in the two directions.

2.2.8 Effects of Timing and Cam Shape

All the results presented from the calculations have been for synchronised timing with a straight cut 45° cam. While this has shown sufficiently clearly the variation in demand within the cycles of knitting the various units, many machines do not have cams of this type. It is possible to introduce different shaped cams into the system. In Appendix 6 a modification is shown for a cam which has a flat bottom while still being cut straight. This has the effect of delaying the time when yarn is robbed back into the structure and will in this manner modify the yarn demand.

A modification for non-synchronised timing can also be introduced. Jacquard fabric is at present produced with synchronised timing. Non-synchronised timing can help to produce a tighter fabric but a positive feed would be required to utilise this facility for jacquard fabrics. Generally in running non-synchronised timing one needle bed is used to draw the total amount of yarn and the second set redistributes this. When the yarn delivery is not constant but dependent upon needle selection the selected needles, that is those on the cylinder, would have to be used to draw the yarn in. Thus the dial needles' knock over must be delayed. In the 1000 unit however the cylinder needles do not knit and so they can not be used to control the drawing of yarn. If the dial needle movement delays sufficiently to

isolate the effects of needles of both sets, the feed point for a dial only unit would be moved and so the feeder could not be set correctly. This problem is removed if positive feed is employed since it is possible to delay the cylinder needles instead of the dial needles because the length fed is determined from the yarn drive. Hence the possibility of producing tighter and more stable jacquard fabric can be realised.

2.3 Yarn Tensions within the Knitting Zone

While the input tension can quite easily be measured it is the build up of tension in the knitting zone which will lead to yarn breakages. Knapton and Munden⁷⁴ predicted that this tension build up can be calculated by examining the contact points within the zone. The actual tension build up will be dependent upon the rob back as well as the yarn properties. With negative feed it is essential that some assumptions about the point of application of the take-up tension and its value are made. As seen in section 1.3.3 this tension is dependent upon the type of loop combination formed and also on how long the previous loop has been held. Nevertheless some estimation of tension build up within the knitting zone can be made.

Using the yarn movement program the data is already available to calculate the angles of contact. This can then be used to calculate the balance point within the structure and hence the maximum tension developed⁹¹. A sub routine to do this is given in Appendix 6. Perhaps the most important point to be considered here is the number of needles in the knitting zone. Obviously the four units 1000, 1100, 1001 and

Table 2.15

Theoretical tension build up in the knitting zone for the jacquard units with a needle at the knock over point, a knock over depth of twice the needle space and an input tension of 5 g.

Unit	Tension at Knock Over (g)
1000	9.4
1100	17.6
1101	31.9

1101 will behave differently. The knock over depth will be a most important factor. If a depth of only half a needle is used, at any one time there will be only one needle moving down the cam in all units. Increasing the cam depth will allow two needles in the 1100, 1001 and 1101 units while leaving the 1000 unit unchanged. When the knock over depth becomes two needle spaces three needles will be on the cam for the 1101 unit. Knock over depth is usually 1.5 to 2.5 needle spaces. For a knock over of two needle spaces (about 3.0 mm) the worst conditions of tension build up are shown in Table 2.15. It can be seen clearly that the highest tensions are created in the 1101 unit and hence there is a greater chance of breakdown during knitting with this unit.

If the feed is direct from the cone, then tension is speed dependent and hence the problem of high tension is compounded. With constant speed positive feed the tension variation within the cycle would cause high tension peaks at the input. This occurs predominantly where the yarn crosses from bed to bed. The storage feed unit can provide constant tension input but the same relative tension build up would occur between the units, resulting in the greater difficulty of knitting the 1101 unit.

2.4 Tension Measurements

Having theoretically considered how the tension varies for the different units within the knitted structures it should be possible to measure some of these effects upon the knitting machine.

Table 2.16

Fabric	Feed Type	Speed (ms/needle space)	Average Tension (g)	Std. dev. (g)	C.V. (%)	Predicted Tension Variation (g)	(%)
plain	off cone	6	7.6	1.6	21	0.3	.6
	IRO	6	7.0	0.4	6	-	-
	+ve	6	3.8	1.3	35	1.2	35
	+ve	6	5.3	1.4	25	1.2	24
	+ve	6	7.1	1.4	20	1.2	17
1x1 rib	off cone	4	15.7	3.2	20	3.9	25
	off cone	6	12.8	3.5	23	3.2	25
	IRO	4	7.5	0.9	11	-	-
	IRO	6	7.0	1.0	13	-	-
	+ve	4	12.7	2.5	19	1.8	14
	+ve	6	12.0	2.4	20	1.8	15
1000	off cone	4	10.3	2.7	26	1.7	17
	off cone	6	7.2	2.1	29	1.3	17
	IRO	4	7.1	0.9	13	-	-
	IRO	6	7.0	1.0	14	-	-
	+ve	4	10.3	2.8	27	2.4	23
	+ve	6	10.4	3.0	29	2.4	23
1100	off cone	4	12.6	3.2	25	3.6	29
	off cone	6	10.1	3.8	38	3.1	29
	IRO	4	7.5	0.9	12	-	-
	IRO	6	7.4	1.0	12	-	-
	+ve	4	10.1	4.6	46	3.2	32
	+ve	6	10.1	4.2	42	3.2	32
1101	off cone	4	13.5	4.5	33	4.0	28
	off cone	6	11.3	3.8	34	3.2	28
	IRO	4	7.4	1.0	12	-	-
	IRO	6	7.3	1.0	13	-	-
	+ve	4	9.3	4.3	40	3.0	31
	+ve	4	9.5	3.9	37	3.0	31

2.4.1 Tension Variation

Using the Rothschild tension measuring apparatus and feeding the results into a Solatron microprocessor voltmeter it is possible to analyse tension data into a mean and standard deviation. This was carried out on a Wildt Mellor Bromley teaching machine. This slow 12 gge machine was used because the response of the Rothschild apparatus is only 300 cycles per second, that is it can only accurately follow a tension fluctuation every 3 ms. The knitting machine was run at its slow and medium speeds. This gave cycle times of 4 ms and 3 ms respectively for plain fabric. The plain fabric was produced with the aid of sinkers while the two bed structures used a dial and cylinder arrangement. A 2/26s (68 Tex) acrylic yarn was used for all the structures with a knock over depth of two needle spaces and the minimum separation between the beds of one needle space.

The results of mean tension and tension variation are shown on Table 2.16 along with predictions taken from Table 2.11 and Table 2.12. If the single knit case is taken first it can be seen that the IRO gives an extremely low variation as would be expected from its tension speed characteristics (see section 1.2.1). The value of variation off the cone is higher than predicted. Here it would be expected that some tension build up around the guides has occurred. With the positive feed producing the same loop length as for the feed from the IRO and directly off the cone, it has been possible to reduce the mean tension quite considerably. However the variation is similar to that predicted in section 2.2.6.2 (about 3.5% at 5 g). Here the actual variation is constant for different speeds as would be expected.

When 1x1 rib is produced the IRO again performs very well in keeping tension variation low, though it has increased considerably over the plain knit case. The level of tension is the same although a faster speed of delivery is required. At the slow speed, feed direct from the cone and through the positive feed perform similarly, both showing about double the standard deviation of the plain. Increasing the speed however increases the tension off the cone while it stays at a similar value from the positive feed. Here the positive feed did not reduce the mean tension as much as in the single knit case. The percentage variation through the positive feed was also not as great as previously though the standard deviation was approximately doubled as expected.

With the jacquard units the IRO again produced results within the same range as for the rib and single knit cases. Both the cone and the positive feed showed some increase in variation but the tension could be kept lower than in the rib case. The variations here are of the order predicted by the yarn movement theory. Off the cone 1000 showed less variation than 1001 and 1101 which are about the same. For the positive feed the 1000 shows an increased standard deviation over the single knit case but about the same as the rib, while 1001 and 1101 are both greater than the rib with 1001 slightly higher. Again it can be seen that the tension off the cone increased with machine speed while that through the positive feed remained constant.

The importance of the IRO unit as a means of reducing tension and tension variation can clearly be seen while the short comings of feeding directly off the cone or through a constant speed positive feed are as predicted. While the

predicted results were taken from the 18 gge calculations as presented previously, the actual results were from fabric produced on a 12 gge machine with a similar ratio between needle spacing and knock over and bed separation distances.

2.4.2 Tension Variations Within a Single Cycle

An attempt was made using the Rothschild tension measuring system to examine the tension variations within a single cycle. The teaching machine was used set up as previously but here the data was fed into a Schlumberger storage oscilloscope. This revealed that the tension measurement system was not able to follow the fluctuations within the cycle. To gain some idea of the shape of the tension trace the machine was turned by hand. The form seemed to be as produced by the yarn movement theory but the results were not conclusive.

Peat and Spicer¹²⁷, in their studies of yarn movement on the knitting machine, showed a tension trace for a single cycle for plain knit which showed a dominant single peak as would be expected. They also presented a movement trace which was of a very similar form to the case with two needles in the zone for half the cycle but again this result could not be considered conclusive.

Any further development in the examination of within cycle tensions would require specially adapted equipment.

2.4.3 Tensions on Flat Bed Machines

The tension was also examined on a flat bed machine using the same measurement equipment. Here only 1x1 rib was knitted and the feed was only from the cone. The mean tension

was found to be 12 g when moving away from the feed side and 8 g when moving towards it. This is as expected for delivery speed difference between the two directions. The IRO will clearly be important to this type of fabric production. It would be expected that the IRO could reduce the mean tension as well as ensure that there are no tension variations between the courses. However, as a separate set of cams is used when travelling in each direction, it is possible to adjust the length input although it is delivered under very different conditions.

2.5 The Use of Positive Feed to Manipulate Yarn Distribution

Positive feed can be used to restrict the amount of yarn in the various units and hence control their structural relationship. As has been seen $2L_{1100}$ is always greater than $L_{1101} + L_{1000}$ for the same settings.

When the settings of KOC, KOD and D are all 2 mm and the machine is running according to the half restricted rob back model, L_{1000} is 4.29, L_{1100} 9.78 and L_{1101} 12.88 mm. To make $2L_{1100} = L_{1101} + L_{1000}$, L_{1100} is required to be 8.59 mm if the other units are not changed. This length is less than the half restricted value but is greater than the length with unrestricted rob back off one loop. This would seem to be well within the knitting range of the machine but would of course increase the peak tension developed in producing the 1100 unit. From Knapton and Munden^{74,92} the input tension change required to alter the rob back by 6% (the change required) would be about 4 g (from 4 to 8 g). This would probably make the tension developed in the knitting zone greater for 1100 than for 1101.

Instead of reducing L_{1100} , L_{1101} could be increased to 15.27 mm. This is approximately the value for no robbing back and so would be difficult to achieve in practice. Similarly increasing L_{1000} would require a length of 6.68 mm for this unit which is greater than L_{1000} with no rob back and so could not be achieved without a change in machine settings.

Manipulations of yarn lengths using the trip tape positive feed were attempted using the four feed Wildt Mellor Bromley 12 gge teaching machine. The first feed was set up to produce 1000, the second 1101 and the other two 1100. It was quite easy to manipulate the yarn length without any knitting difficulties. The fabric was produced with the ratio $L_{1101} : L_{1000}$ equal to 3.05. Initially L_{1100} was about 21.6 mm but was reduced to 20.2 mm using the positive feed without changing the cam settings. A tension increase of 5 g to 10 g was noticed. The ratio 2.2 : 1 for $L_{1101} : L_{1000}$ was also used. $L_{1100} : L_{1000}$ was initially at 1.8 : 1 and here it was possible to reduce L_{1100} so that $L_{1100} : L_{1000}$ was 1.6 : 1 as required. The resulting tension increase was 5 to 9 g mean for the 1100 units, the others being knitted at 5 g. In both these cases the structure was noticeably tighter and narrower, as expected by the shorter length of yarn being drawn, and approached the dimensions expected for Swiss double piqué.

Here it can be seen clearly that a positive feed system can reduce the L_{1100} unit without need for change of settings. Positive feed, if it is possible in the jacquard case, could be used to control the lengths so as to keep the relationship between the various units at their best possible level.

2.6 Conclusion and Yarn Feed Requirements

A yarn movement model has been successfully developed which fits well to the observed practical results by predicting the lengths of the repeat units for given cam settings and the yarn demand variations within the unit. From this it has been possible to see the effects of yarn feed devices and predict the requirements for improving the feed. At present the IRO or storage feed unit is undoubtedly the best device for reducing the tension on the yarn and hence making it much easier to knit especially in the patterned fabric case. However this does not control how the yarn is distributed to the various units. A problem still exists with the variation between the dimensional and tightness properties of these units. The constant speed positive feed unit, while it can control the length delivered to repeated units, leads to a large variation in tension within the knitting cycle. This means that even if this type of device could be developed to feed for jacquards, tension conditions at the feed could not be kept very low because of the need for adequate yarn control. The positive feed however can be successfully used to control the distribution between the units by shortening L_{1100} and hence bringing the properties of this unit in line with the double piqué type units. A successful knitting feed could be developed by breaking the individual units into about twelve steps. This would then enable the actual yarn demands to be followed closely. The steps, while of the same length, must be delivered at varied rates. The approximate rate to produce a satisfactory system would be about 2,000 steps per second. With equipment which can respond at this rate it would be possible also to

positively feed patterned fabric both in the circular and flat machine cases. This could be done with a system which produces only three steps per cycle (500 steps/s) but the tension variation within the cycle would be large.

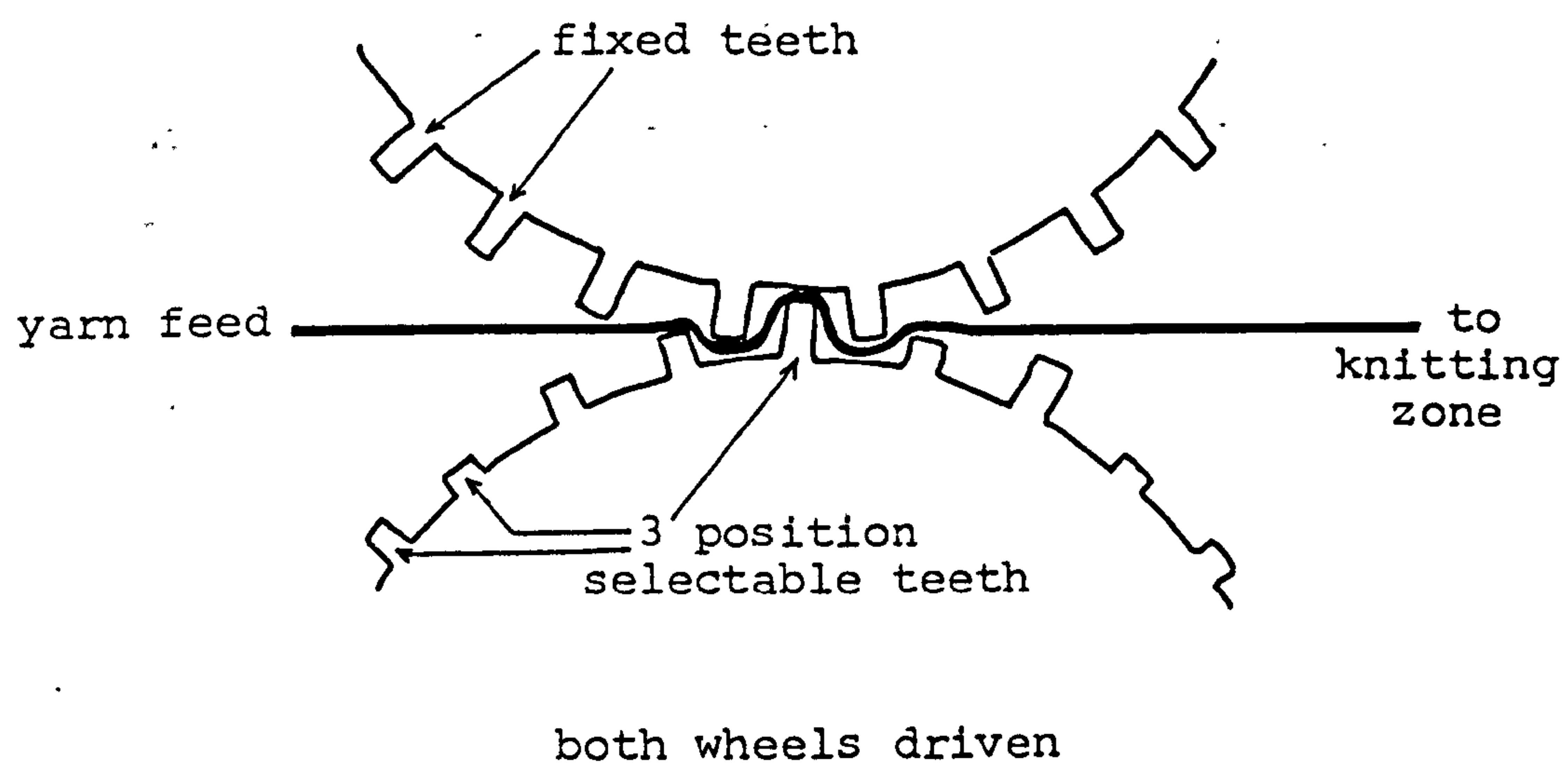


Figure 3.1 Assisted jacquard feed using interlocking "gear" wheels.

Chapter 3

Movement Control Mechanisms

The development of a feed system which can deliver the required amount of yarn to the length units within the bird's eye backed jacquard structure must be based upon needle selection data, which can then be used to determine and present the right amount of yarn. The previous chapter has shown the difficulties involved when the yarn demand requirements are averaged and the yarn fed to this average at a constant rate. The basic delivery time for each of the three length groups is 6 ms for an 18 gge 30 inch diameter circular machine. Within this time the yarn requirements must be determined and then presented. It may thus be necessary to analyse the requirements separately which, as discussed in section 1.3.4, would not be difficult using a microprocessor.

A purely mechanical solution does exist. An arrangement could be developed similar to that in use in tufted carpet manufacture¹⁶³ to form a "sculptured" pile. Here a device rather like a pattern wheel is used to deliver a predetermined length in a similar manner to a sinker wheel. An arrangement of this type is shown in Figure 3.1. A wheel with selectable pattern bits is intermeshed with a regular toothed wheel. Depending on the selection of teeth (in a three position system) the three lengths can be prepared and then, by synchronising the drive of this wheel, presented to the knitting zone. This method would have severe limitations upon the repeat size. The mechanical complexity and setting up time would be considerable. Also this system, as in the

sinker wheel machine, does not positively hold the yarn and therefore assists the feed rather than positively controlling it.

To store data quickly and accurately considerable advantage in terms of cost and store size is given by electronic means, as already used for needle selection during knitting^{150,151}. Here an electronic signal is used to put the needle butt into either a knit or miss position with the translation from electronic signal to mechanical movement achieved by a solenoid. The more critical positioning of the needle during loop formation is still cam controlled. Thus this operates as an electro-mechanical system. As in the case of electronic needle selection, the yarn feed information can be stored in an electronic device and delivered to an electro-mechanical device to drive the yarn. As seen previously, there are three different units of length required between four successive needles for bird's eye backed jacquard fabrics. Hence a three way selection system is required. There is again a parallel in needle selection where the split is usually divided into tuck/miss and knit/tuck, giving an overall knit, tuck, miss selection but only requiring two splitting situations.

An electro-mechanical transmission by means of a clutch has been proposed in patent application only¹⁶⁴. It is proposed that a clutch can be used to switch between two pre-set speeds. Not only is a clutch system of this type difficult to operate at knitting speeds but in the proposal only two knitting speeds are offered which is insufficient for most knitting situations. In addition a specially built three way selection system seems to be unnecessarily

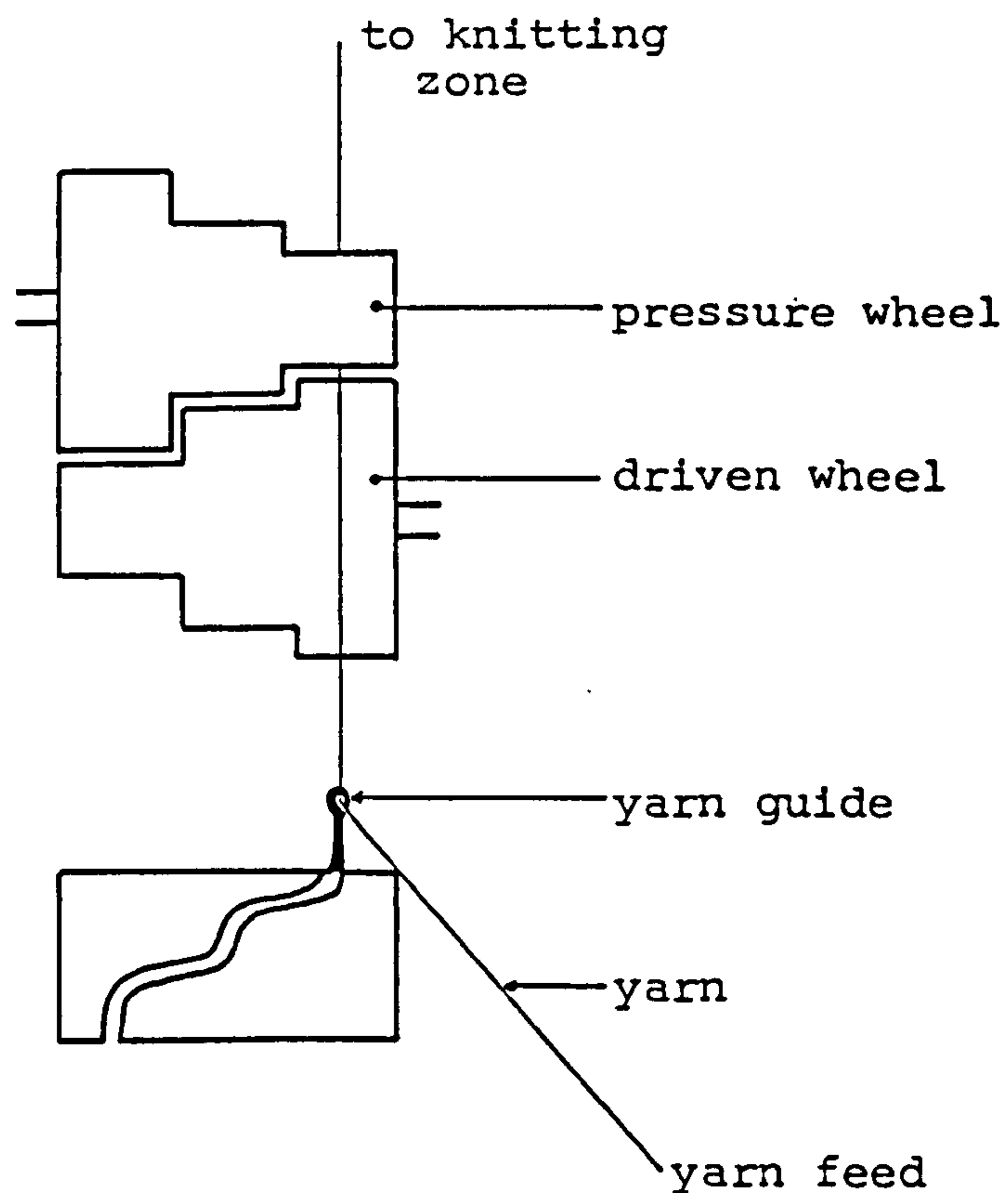


Figure 3.2 Feed system using a three speed driving wheel with the yarn position determined by a cam controlling the yarn guide position.

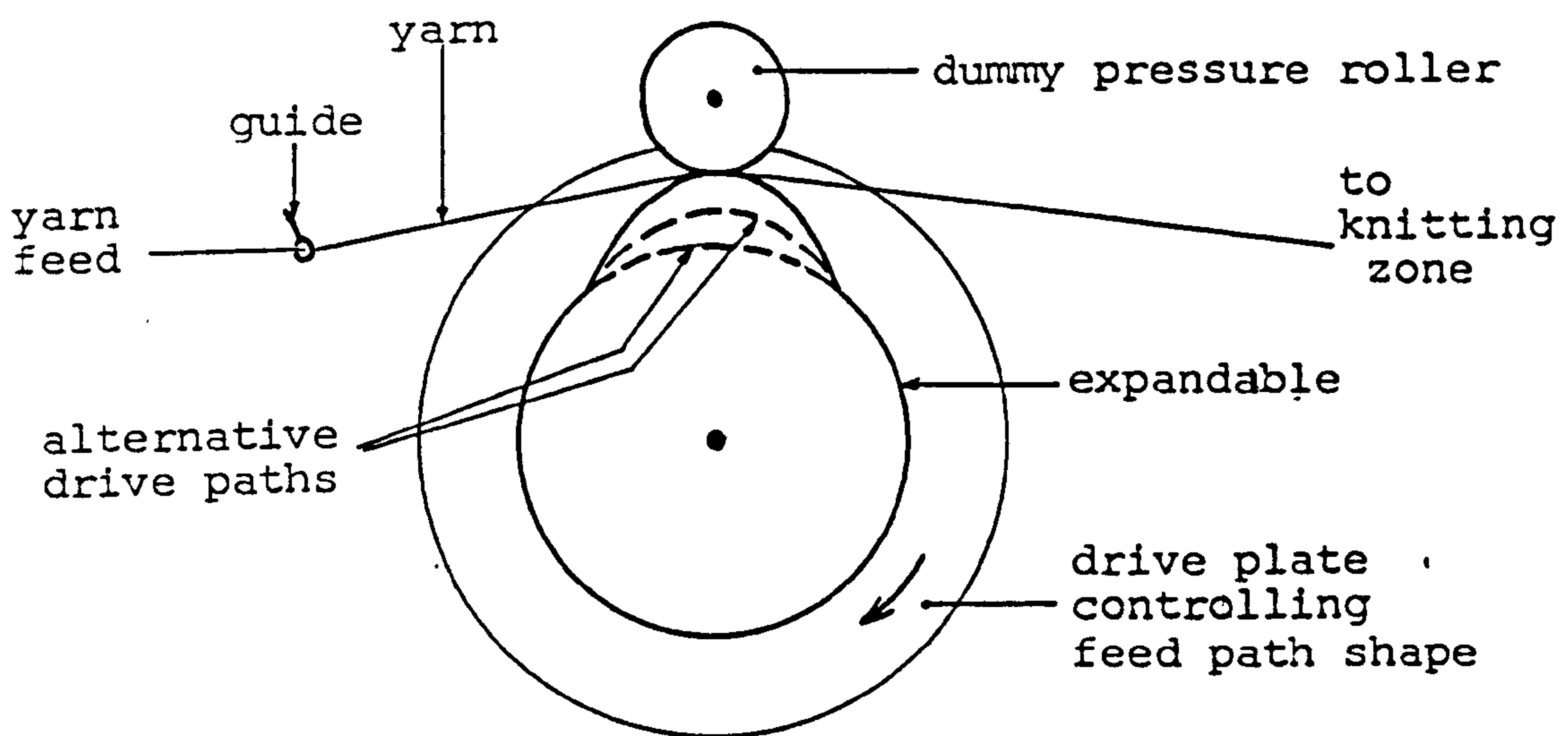


Figure 3.3 Feed system using an expandable drive wheel.

complicated.

Another possibility exists in the development of a tapered roller pair in which a yarn guide is positioned as appropriate or (as in warp knitting¹⁶⁵) a sliding ring couples the relative drive ratios. This type of system is presented diagrammatically in Figure 3.2. Here a three way selection system must be implemented for guide or drive ring position. The warp knitting system offers only an extremely low speed response and while a free running guide system may offer less speed restriction, shifting the yarn guiding position would seem to offer an extremely bulky and unstable feed system.

To improve the situation, still using basically a splitter with cam positioning, an expandable drive system with a demand shaped profile could be used. Here the three way selection is similar to the previous one but the feed point remains static while an expandable path drive is used. This is shown diagrammatically in Figure 3.3. A dummy roller is used to positively nip the yarn against the expandable drive.

All these systems requiring precision purpose made camming will prove extremely expensive and difficult to implement. It is difficult to envisage any system of this type which will not double the amount of precision engineering required in building knitting machines. While no precision would be required beyond that already existing in knitting machines for needle movement, the cost of such devices would seem prohibitive.

As well as the solenoid, another much used and loved device uses an electrically created magnetic field to produce mechanical movement. This device, which produces

rotational rather than linear movement, is the electric motor. A conventional motor suffers from the fact that the actual movement is not precisely determined by the electrical signal presented. The movement must be sensed and the information fed back to the controls so that knowledge of the actual mechanical movement is maintained. This type of closed loop control system, requiring sensing transducers and control switching, would be extremely difficult to implement at high speed. A development on the basic electric motor is a stepper motor¹⁶⁶ in which the electric signal is presented to the motor as a pulse and for each pulse the motor gives a precise angular rotation of its shaft. This enables open loop control to be used in which no positioning transducers are required. The characteristics of this device, which is widely used in computer control situations, would seem to offer a mechanically simple system of controlling yarn movement electronically. A proposal¹⁶⁷ for a feed system for a jacquard knitting machine based on a stepper motor has been put forward but no development in respect of this proposal has emerged. This proposal relates to the average yarn demand not the fluctuations from needle to needle.

3.1 Stepper Motors

A stepper motor¹⁶⁶ is a motor possessing the ability to rotate in either direction as well as stop and start at various mechanical positions. The shaft (or rotor) moves in precise angular increments or steps for each input excitation change. The displacement is repeated for each input step command. The result of this type of movement is the motor's ability to accurately place the rotor in a known repeatable

position.

The stepper motor allows control of position, velocity, distance and direction. Because each step moves the shaft to a known position, the only shaft position error (regardless of distance or direction of movement) will amount to the single step accuracy. This accuracy is typically 5% of one step^{168,169}. Stepper motors are available organised to give different numbers of steps per revolution. Typical values are 200, 180, 144, 72, 24 and 12^{170,171}. Microstepping¹⁷² can be achieved on most motors by dividing each step into 2, 4 or more steps.

As the driver knows the shaft position for all but high speed performance drives, the system can be run in an open loop mode (ie. without the need for feedback position potentiometers, encoders or other transducers). This feature makes the stepper motor attractive over a DC servomotor system, which must be run in a closed loop mode. Stepper motors normally available are, however, limited to less than one horsepower (746 watts). A DC servomotor system will be more suitable for control purposes above this power.

Because of the stepper motor's basic brushless construction^{168,172} it is extremely robust and reliable and has a high life expectancy. Two basic types of stepper motor are produced : variable reluctance and permanent magnet, while a third hybrid variety combining features of both is commonly available.

3.1.1 Variable Reluctance Stepper Motors

The variable reluctance stepper motor^{170,171} has a multiple tooth soft iron rotor with a three or four phase

wound stator. The numbers of teeth on the stator and rotor differ so that successive shifts in the stator field result in rotary motion with the rotor moving to successive positions at which the magnetic path reluctance is minimised. Direction of rotation is determined by the sequence in which the stator coils are energised and the basic step size depends upon the number of teeth that can be accommodated in a given diameter. Typical angles are 7.5° and 15° . When the motor is de-energised there is no residual or detent torque and the rotor is free to rotate.

3.1.2 Permanent Magnet Stepper Motors

The permanent magnet stepper motor's^{170,171} basis of operation is taken from the basic permanent magnet characteristic that like poles repel while unlike poles attract. The rotor consists of a two pole or multiple pole cylindrical permanent magnet which is radially magnetised. The stator of this type of motor is usually a multi-phase wound system. Higher torques are developed by this type of motor than the variable reluctance type owing to the permanent magnet rotor, and a detent torque is produced when the stator is de-energised due to the action of the permanent magnet. Both three and four phase units are available and step angles range from 30° to 120° with direction of rotation again being determined by the sequence in which the stator coils are energised.

3.1.3 Hybrid Stepper Motors

As the name suggests, the hybrid stepper motor is a cross between the permanent magnet and the variable reluctance

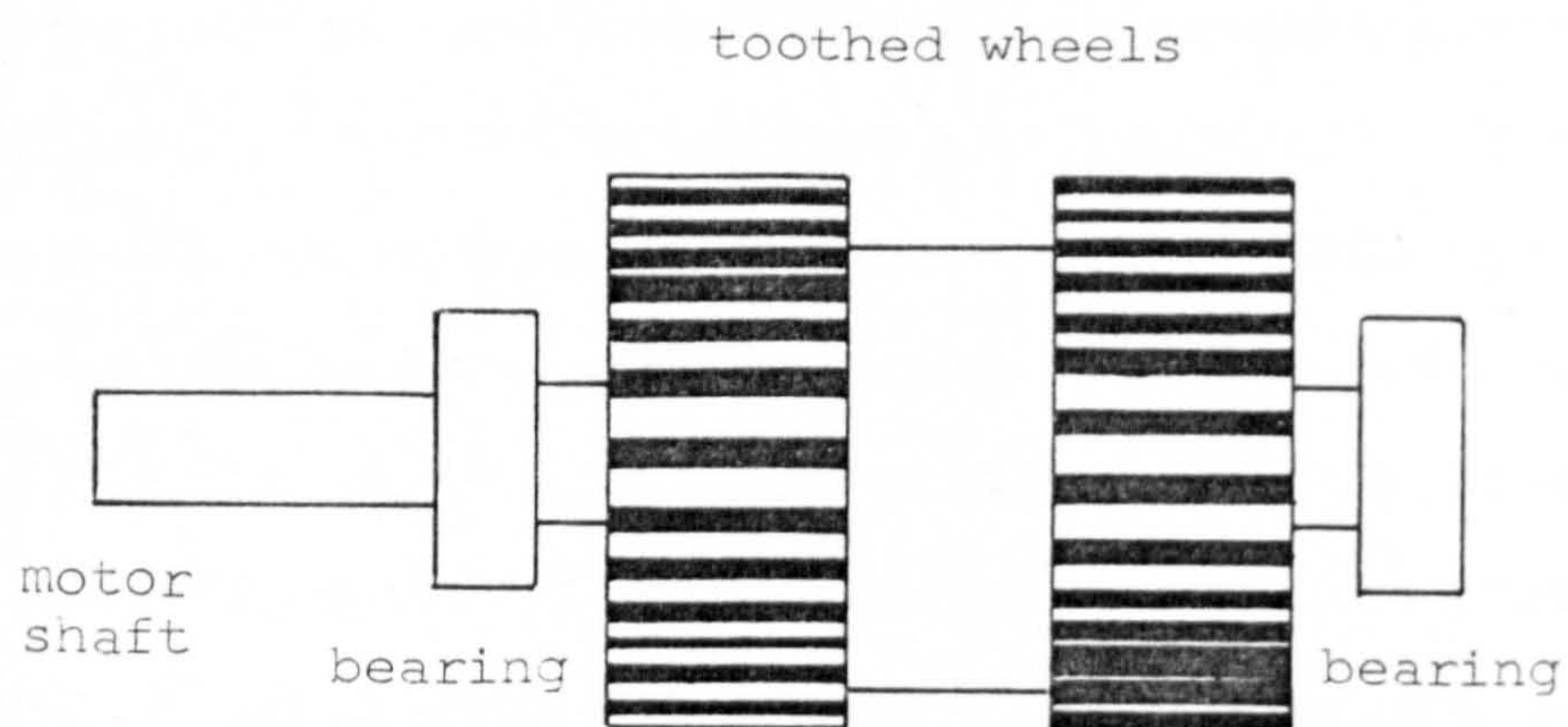


Figure 3.4 Stepper motor rotor.

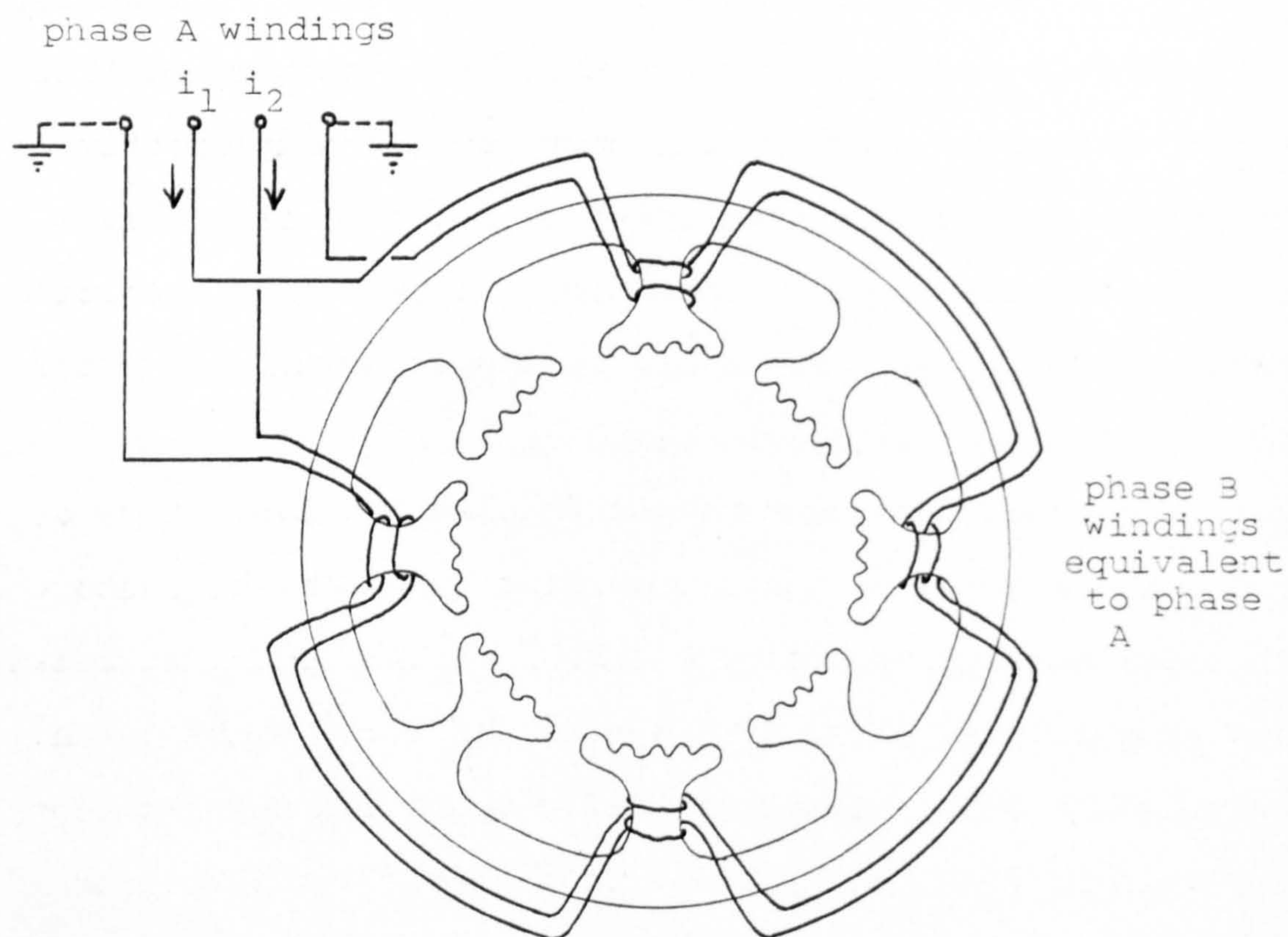


Figure 3.5 Stepper motor stator showing phase A windings only.

types. It is often referred to as a permanent magnet motor because a permanent magnet is used. They form the bulk of the stepper motors commercially available^{169,170,172}, with step angles from 0.45° to 5° . The small step angles result in a considerably higher torque than that developed in motors with higher step angles. The hybrid motor has an axially magnetised permanent magnet providing homopolar excitation between the rotor, which is in two differently oriented parts, and a heteropolar excited wound stator. The motor has a gear like hub on each end of the magnet (rotor) as shown in Figure 3.4. The north end of the rotor has teeth that are 180° out of phase with the south end. The stator or stationary part of the motor also has teeth with the magnetic poles generated by the windings as shown in Figure 3.5. The number of teeth on the rotor is different from the stator, so that all the teeth of the rotor will never be lined up exactly with those on the stator. It is this that actually creates the predicted movement of the rotor, the magnetic attraction of each position being between the closest stator and rotor teeth.

A common motor construction which gives 1.8° steps or 200 steps per revolution has 8 salient poles on the stator, each pole having five teeth. A "ghost" tooth is formed between adjacent poles and this gives a total of forty eight teeth. Each pole cap of the rotor has fifty teeth and the two caps are misaligned by half a tooth. This develops two hundred half pole steps on the rotor by switching the stator in normal operation.

The stator is often bifilar wound, in which two windings are assembled on each pole. The wire used is of a thinner

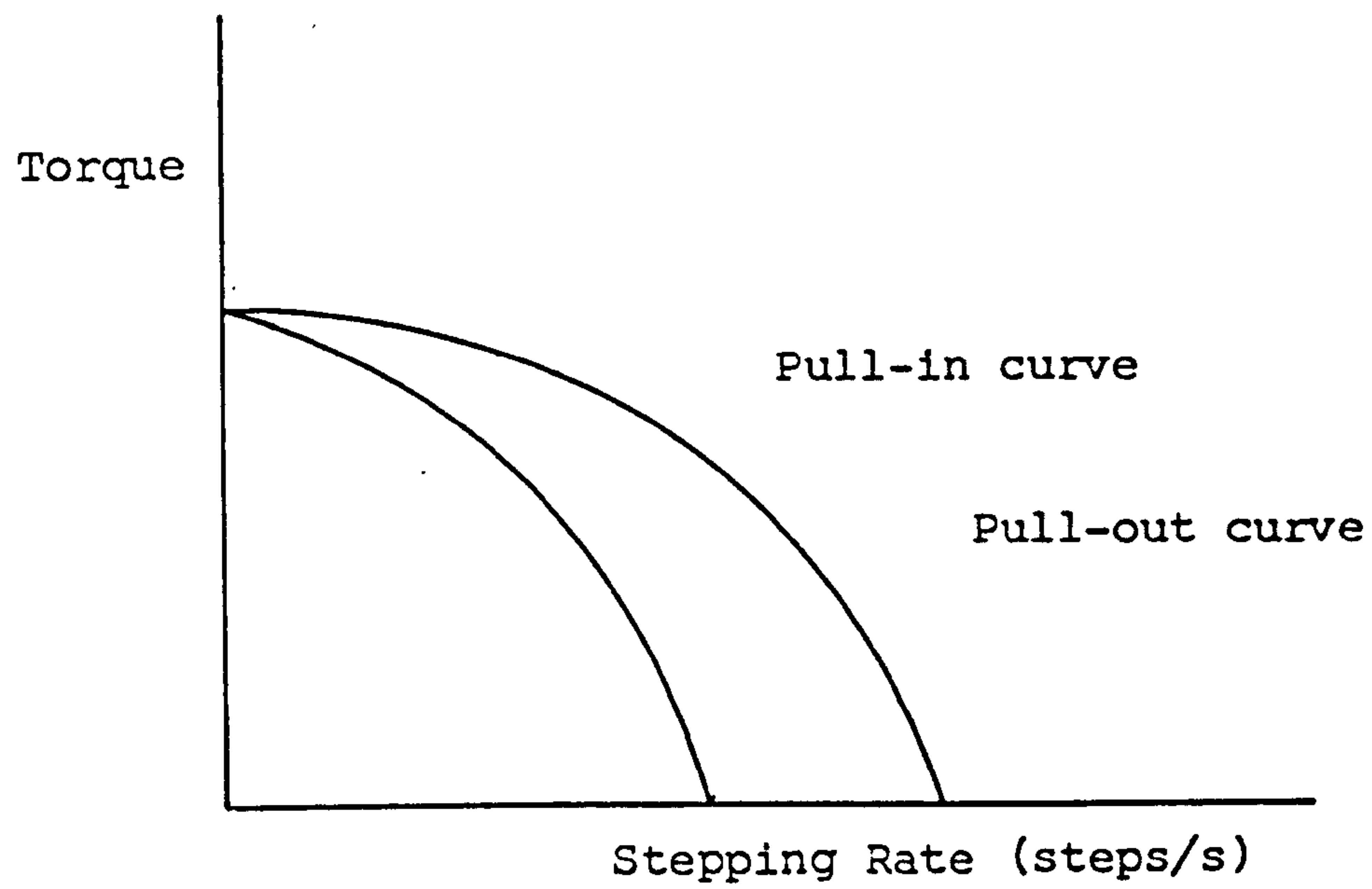


Figure 3.6: General form of performance curves for stepper motors.

gauge than a standard winding so that it can fit into the same frame size. This bifilar winding offers advantages in terms of performance and simplifies the drive arrangements¹⁷¹.

3.1.4 Performance of Stepper Motors

Performance curves are generally presented for stepper motors as shown in Figure 3.6. The pull-in curve represents the speed at which the motor will instantaneously start and stop without loss or addition of steps. This curve is dependent on the inertia of the load on the system as well as the motor characteristics. Higher stepping rates can be achieved by gradually increasing the pulse rate of the motor until a point is reached at which synchronisation is lost and the motor fails to rotate. This represents the maximum performance of the motor. The area between the two curves is known as the slewing region, in which the motor can be operated provided it is accelerated and decelerated without losing synchronisation and is only stopped and started from the pull-in curve.

Performance of the motor/load combination not only depends upon the value of the load and its friction but also upon the total load inertia. The maximum stepping rate is also determined by the type of electronic drive used and the ability of this drive to build up current in the inductive windings of the motor.

For a yarn feed application a high resolution motor is needed which rapidly responds to changes. Here the choice is somewhat limited. Availability makes it virtually necessary to use a two hundred step per revolution hybrid motor. The variable reluctance and permanent magnet motors do not

provide the high speed response in sizes easily available. One advantage of the variable reluctance motor is that when the power is off it can be turned freely. This would allow easy setting up of knitting machines. At present on positive feeds a release device is a necessity^{77,78} and this could be utilised with the hybrid motor.

From this brief examination of stepper motors it has been found that a hybrid motor with a suitable drive arrangement will give the performance required. It seems that 1,000 steps per second is a reasonable value to expect in the stop-start condition, while at maximum performance 5,000 steps per second can easily be reached. A choice of several drive arrangements is available. The motors are typically available with a large range of motor coil resistances allowing a wide variety of currents¹⁷². Special types are also available with low inertia rotors for applications where high accelerations are required.

3.2 Coil Switching

Rotation of a stepper motor is achieved by feeding current to the stator coils in a predetermined sequence. Reverse direction is achieved by reversing the switching sequence. Microstepping can be achieved by altering the stepping sequence fed. This achieves smaller step angles than the nominal for a given motor. The motor performance is largely dependent upon the drive system used. The critical factor is how fast the current can be delivered to the inductive motor coils. As stepping rates are increased the coil inductance limits the current in the coils and the output torque falls off. The simplest method to achieve

increased performance of a motor is to use resistive forcing. Here the motor time constant is reduced by introducing an external resistor in series with the motor coil. This is referred to as R/L or resistance limiting drive.

The motor time constant, T, is given by:

$$T = \frac{H}{R_m + R_s}$$

where H = coil inductance

R_m = coil resistance

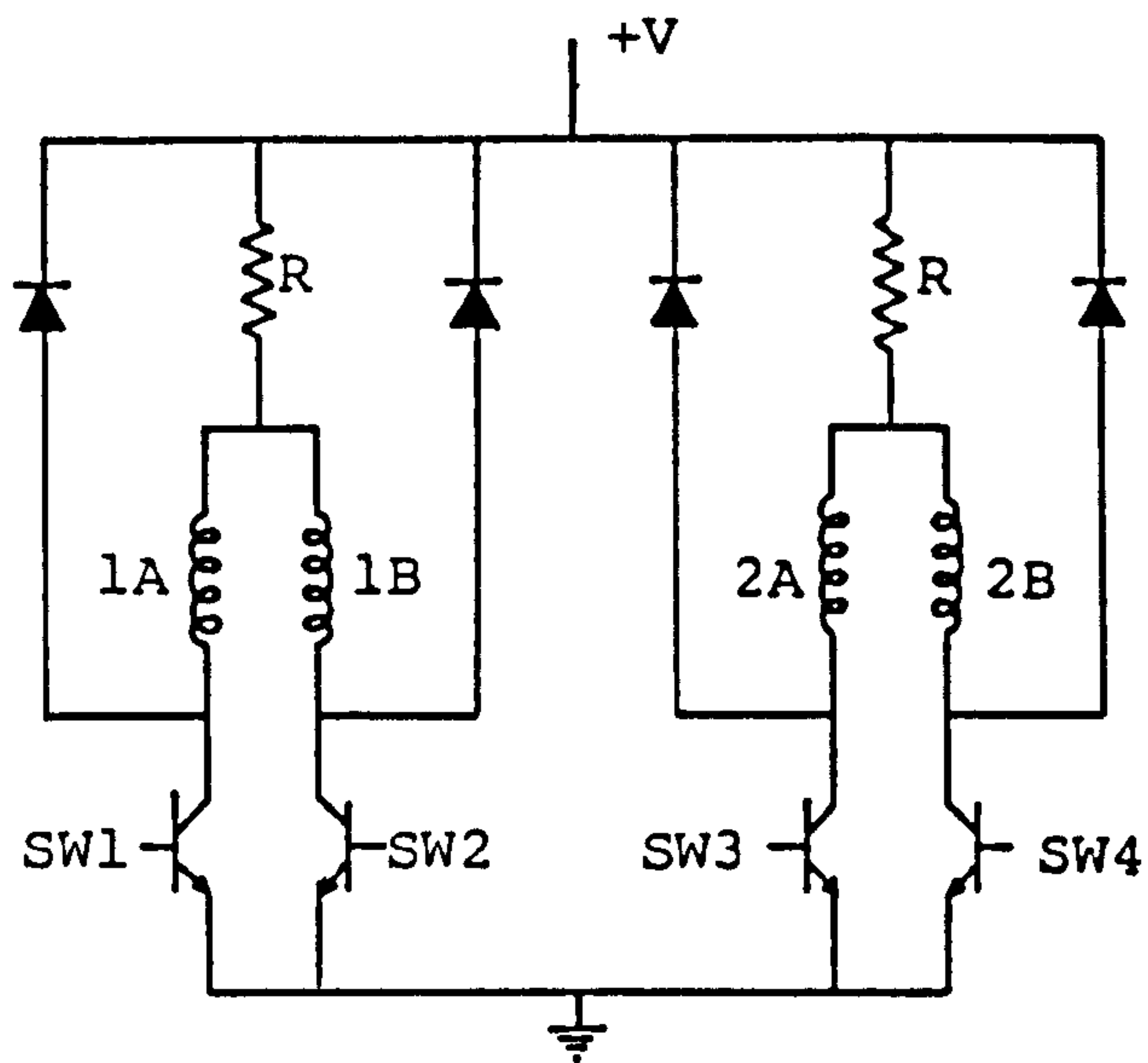
R_s = external resistance

To maintain the same current level when external resistance is introduced, the voltage drop across the resistor must be accounted for by increasing the supply voltage. The rated standstill current in the motor must not be exceeded. In practice a series resistor (R_s) is used which is a multiple of the coil resistance (R_m). By using $R_s = 4.5 R_m$ the maximum pulse rate can be increased to 10,000 steps/s compared with 1,000 steps/s for $R_s = 0$ ^{173,174}. Here of course the current at standstill is maintained by increasing the supply voltage. The high speed performance of the motor is proportional to the voltage of the driver. The low speed performance is however dependent on the type of driver used.

Two basic drive arrangements exist: unipolar and bipolar. The unipolar switches the current in only one direction through the motor coils while the bipolar can switch the current in both directions. These will be considered separately.

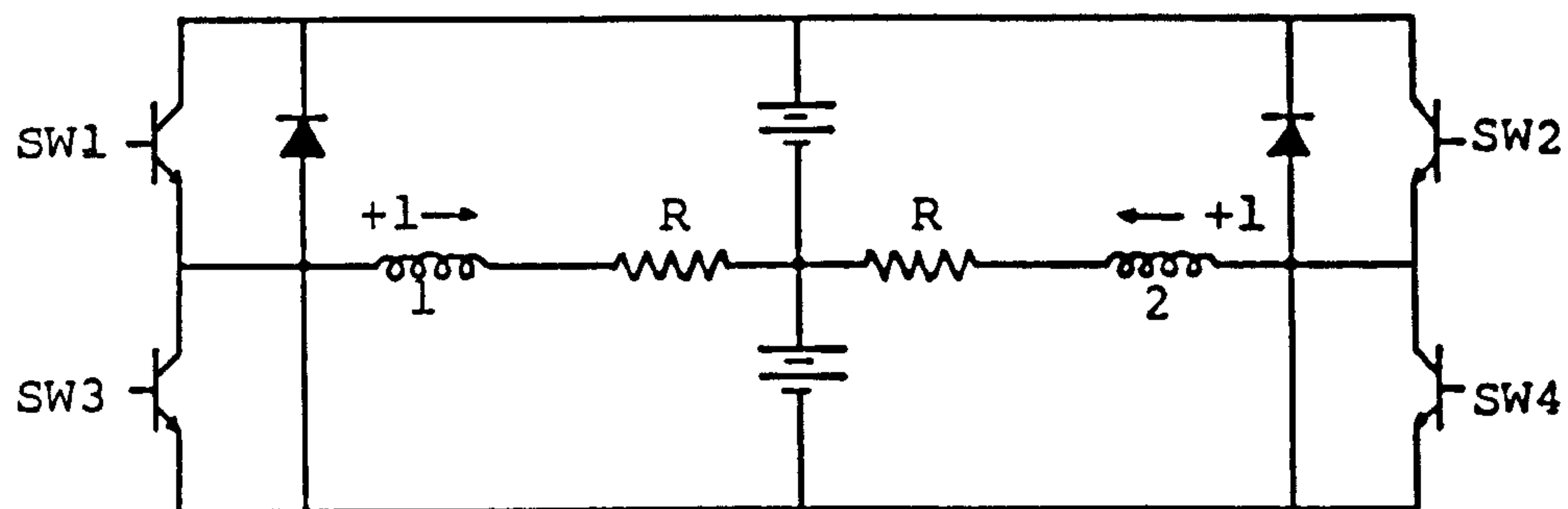
3.2.1 Unipolar R/L Drive

Here each of the coils is switched to ground to allow



Switching	Step	Coil			
		1A	1B	2A	2B
full step	1	1	0	0	1
	2	1	0	1	0
	3	0	1	1	0
	4	0	1	0	1
	1	1	0	0	1
half step	1	1	0	0	1
	2	1	0	0	0
	3	1	0	1	0
	4	0	0	1	0
	5	0	1	1	0
	6	0	1	0	0
	7	0	1	0	1
	8	0	0	0	1
	1	1	0	0	1

Figure 3.7 Unipolar R/L drive arrangement and truth table to step a nominal 200 step bifilar wound motor either 200 full steps or 400 half steps per motor revolution.



Switching	Step	Coil	
		1	2
full step	1	+1	+1
	2	+1	-1
	3	-1	-1
	4	-1	+1
	1	+1	+1
half step	1	+1	+1
	2	+1	0
	3	+1	-1
	4	0	-1
	5	-1	-1
	6	-1	0
	7	-1	+1
	8	0	+1
	1	+1	+1

Figure 3.8 Bipolar R/L drive arrangement with two power supplies and truth tables for full or half step operation.

current to flow. A drive arrangement with a truth table to step a nominal 200 step motor either 200 full steps or 400 half steps per motor revolution is given in Figure 3.7. For the full stepping sequence the coils are always used in pairs and hence maximum torque can be used for all steps. However under these conditions there are often sections in the motor drive where resonance can occur. Here the natural frequency of the system takes over and drive control is lost. The rotor stops turning and vibrates. Half step operation is very effective in reducing or eliminating resonances¹⁷². It also reduces overshoot and settling time on the final step, and it reduces shock and acoustic noise on the drive system which is connected to the motor shaft. When running, the operation is smoother due to the smaller step, which is important in some applications such as plotters or surface finish operations. Full step performance can be equalled with half step operation by doubling the switching rate. For a given shaft rpm the half step torque will be the same as full step torque at high speeds but will be decreased by up to 10% at speeds lower than 1000 steps/s. This is due to the "weak" steps where only one coil is utilised.

Unipolar drives are cheap and simple, requiring few components and only a single polarity power supply. However the efficiency of the system is fairly low as current is only driven through the coils in one direction.

3.2.2 Bipolar R/L Drive

The bipolar drive sends current through the coils in both directions and hence all coils can be utilised at the same time. Figure 3.8 shows the drive connections for a

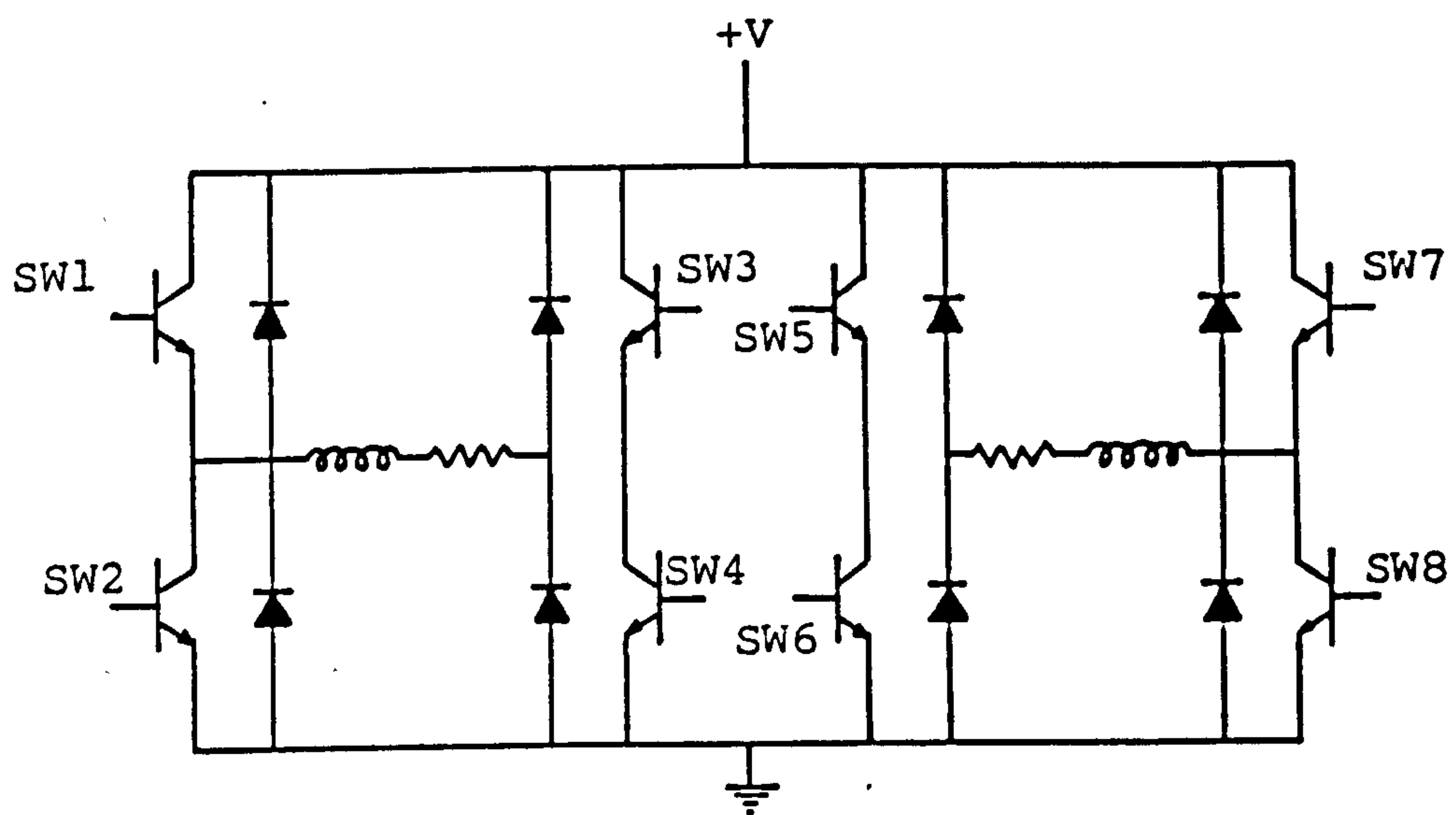


Figure 3.9 Bipolar R/L "H" drive with one power supply.

bipolar drive arrangement using two power supplies (or a bidirectional supply) and truth tables to enable full and half step operation. Here only two coils are used. This system can achieve¹⁷² 30% more mechanical power than the unipolar R/L drive for the same electrical power input or the same output power with half the electric input. This is especially important at low speeds and in the stop-start region where 20 to 40% more torque is developed up to 1,000 steps/s. This system however requires a bipolar power supply and hence additional cost.

An alternative to using two power supplies is to use a transistor bridge for each phase of the drive. This is referred to as an "H" drive and is shown in Figure 3.9. Here the same bipolar performance can be achieved but the number of switching components is considerably increased. This will approximately double the cost of components over the unipolar drive arrangement for a given current.

When using the bipolar bridge it must be ensured that two transistors in one arm are not switched on at the same time which would short out the power supply. This would result at least in taking out the transistors and would probably damage the power supply and perhaps the motor. In this case it is better to use the half step sequence where one coil is put in a neutral position before reversing the current, hence lessening the risk of both transistors being on at the same time.

The cost of components will increase considerably if currents are used which require heat sinks and other heat dissipation methods. However as long as currents are kept low, bipolar switching offers the cheapest system for

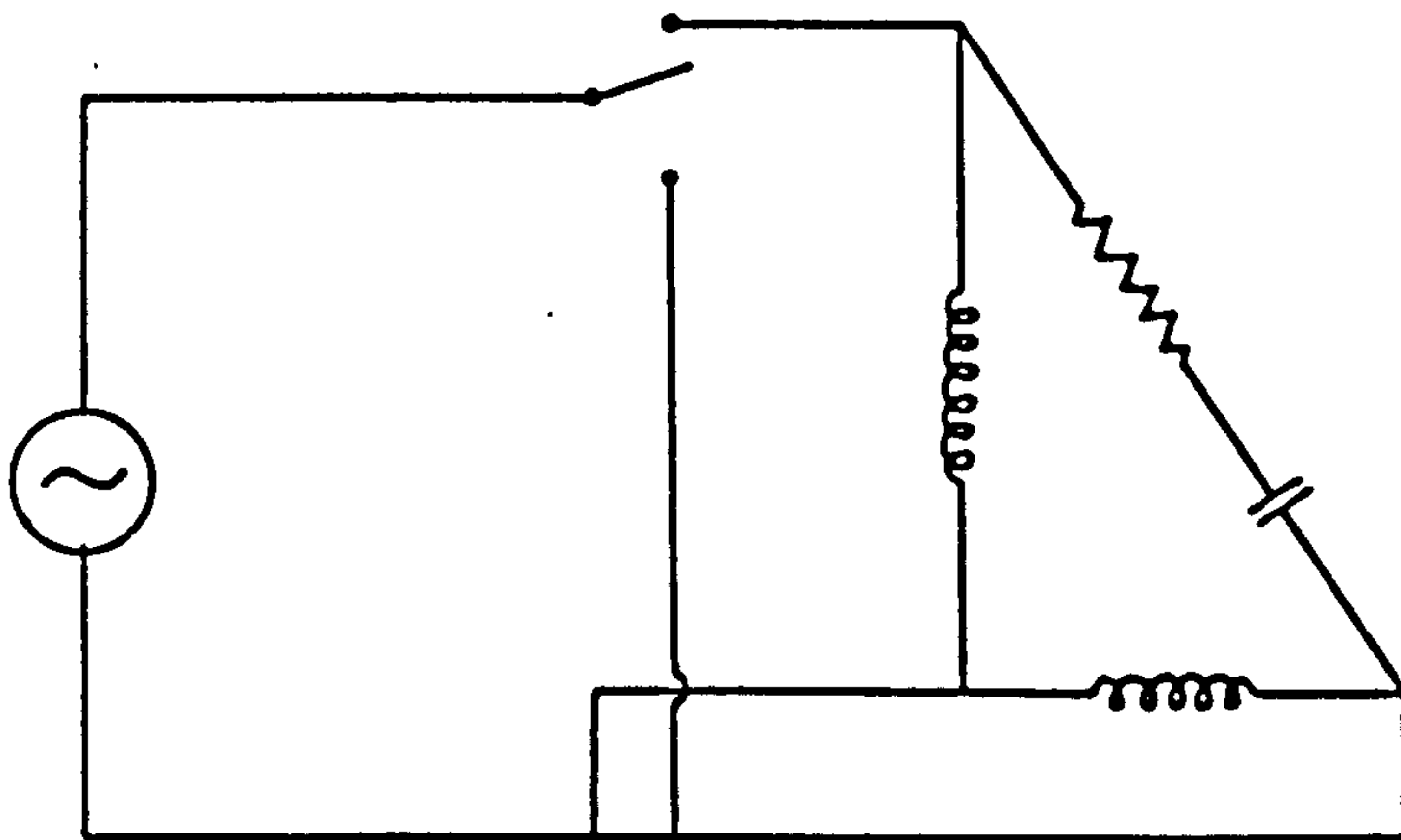


Figure 3.10 AC synchronous drive with phase shift network.

a given performance. This means that the current must be kept below 1 A per phase to keep down the heat dissipation necessary in series resistors and transistors. (At 0.8 A 15 watts of heat are generated compared with 35 watts at 1.5 A.)

Motors must be chosen with suitable winding impedances for the drive currents used. The torque performance of motors with different impedances is essentially the same up to 1,000 steps/s but higher for lower impedance motors above this speed. The improved high speed performance is obtained through increased current for lower impedance motors. With any resistance forcing method a great deal of energy is lost especially at low speeds and when the motor is stationary. Under these conditions power is used very inefficiently.

3.2.3 AC Synchronous Drive

Stepper motors can also be driven directly from an AC power supply. When operation in this mode is required either a dual phase supply or a single supply with a phase shift network is needed. A single supply drive with a phase shift network for two coils is shown in Figure 3.10. Here provision for direction change is provided by a switch. To produce a variable speed control a two phase variable supply would be necessary. Limitations in performance would be similar in a DC switching situation, with the time to get the current into the coils being the performance restriction.

3.2.4 Current Regulated Drives

To overcome the inefficiency of the R/L system at low speeds several arrangements are possible which vary

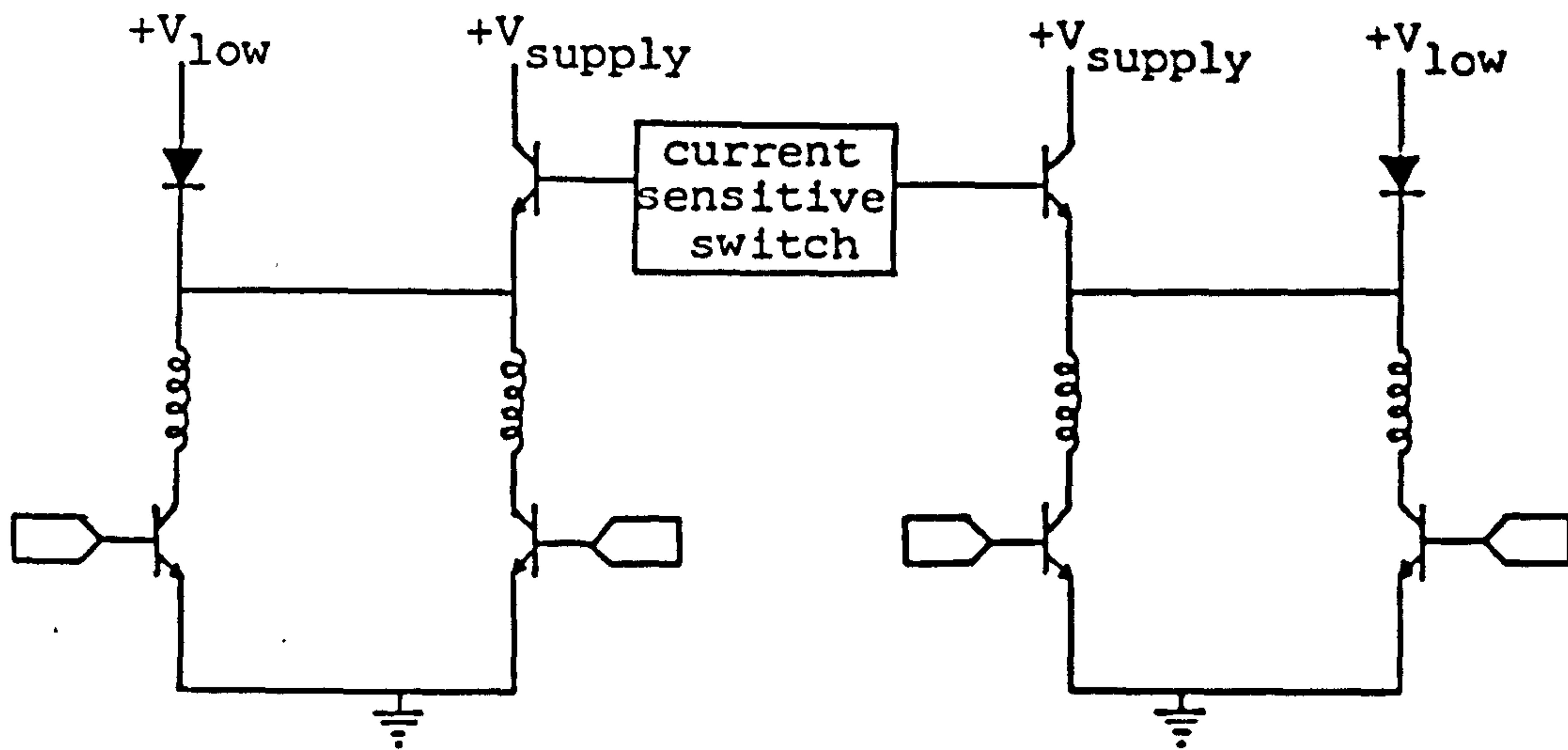


Figure 3.11 Dual voltage supply

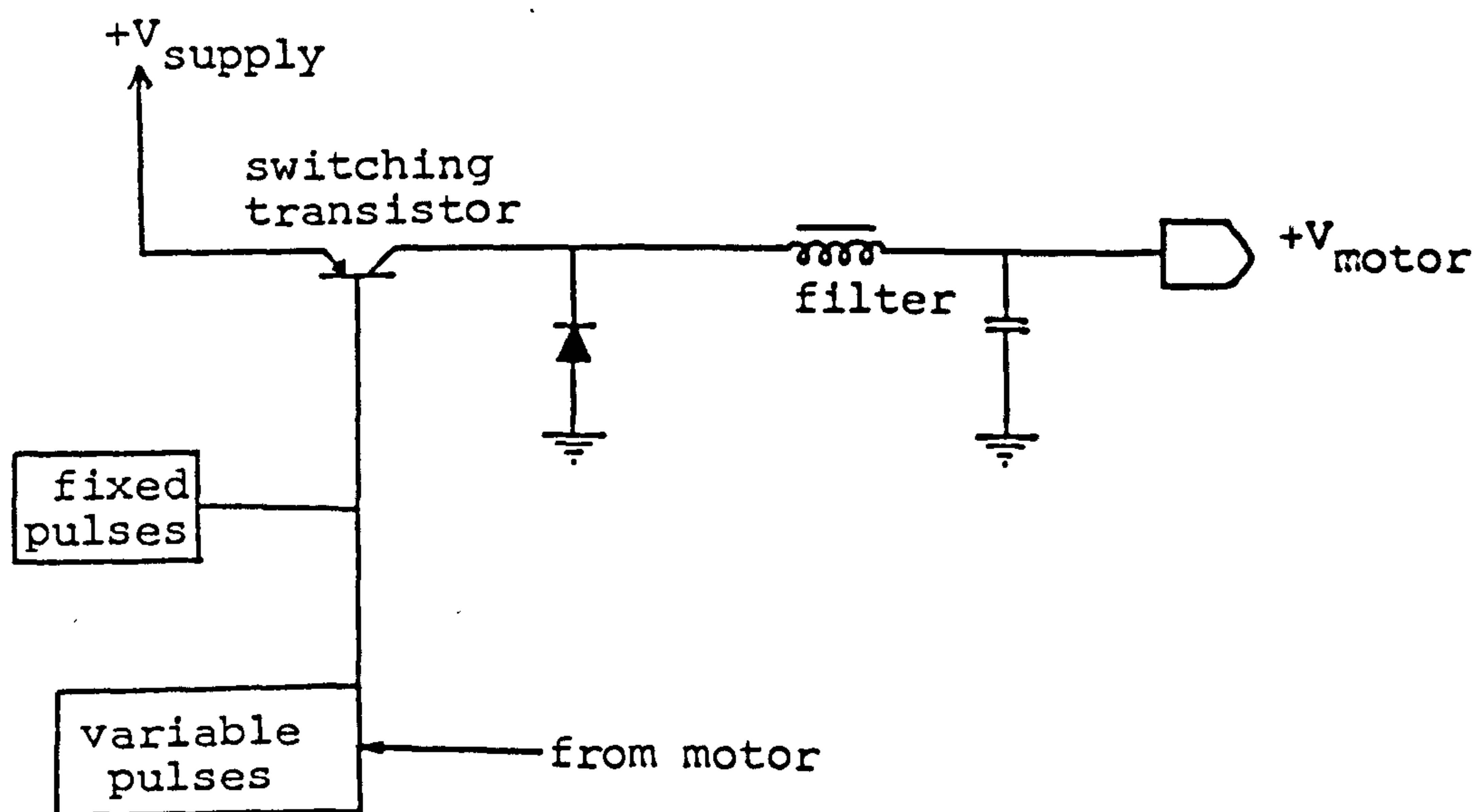


Figure 3.12 Variable voltage supply

the rate of current delivered depending on the speed at which the motor is running. The most important of these are dual voltage supply, variable voltage supply and current limiting chopper drive. These all require increased complication in the drive system and hence higher cost but where power consumption is important the increased drive expense may easily be warranted.

3.2.4.1 Dual Voltage Supply

This scheme shown in Figure 3.11, employs two power supplies: one high and one low voltage. The high voltage supply is switched out of the coils when the current in them rises above a pre-set level. Current is maintained in the coils at slow speeds and standstill by means of V_{low} and is able to rapidly build up at high stepping speeds by means of the high voltage, V_{supply} .

3.2.4.2 Variable Voltage Supply

In this system, as shown in Figure 3.12 only one supply is needed. A fixed pulse independent of the motor is initially used to switch power to the motor coil. A second pulse train whose rate is determined by the motor speed also controls through the transistor switch. As the motor accelerates the switching rate increases and hence the voltage supplied to the motor increases. This again aids high speed performance without the need for current limiting resistors.

3.2.4.3 Chopper Drive

This drive in a bipolar form is covered by patents owned by Sigma Instruments, Inc.^{175,176}. A unipolar chopper

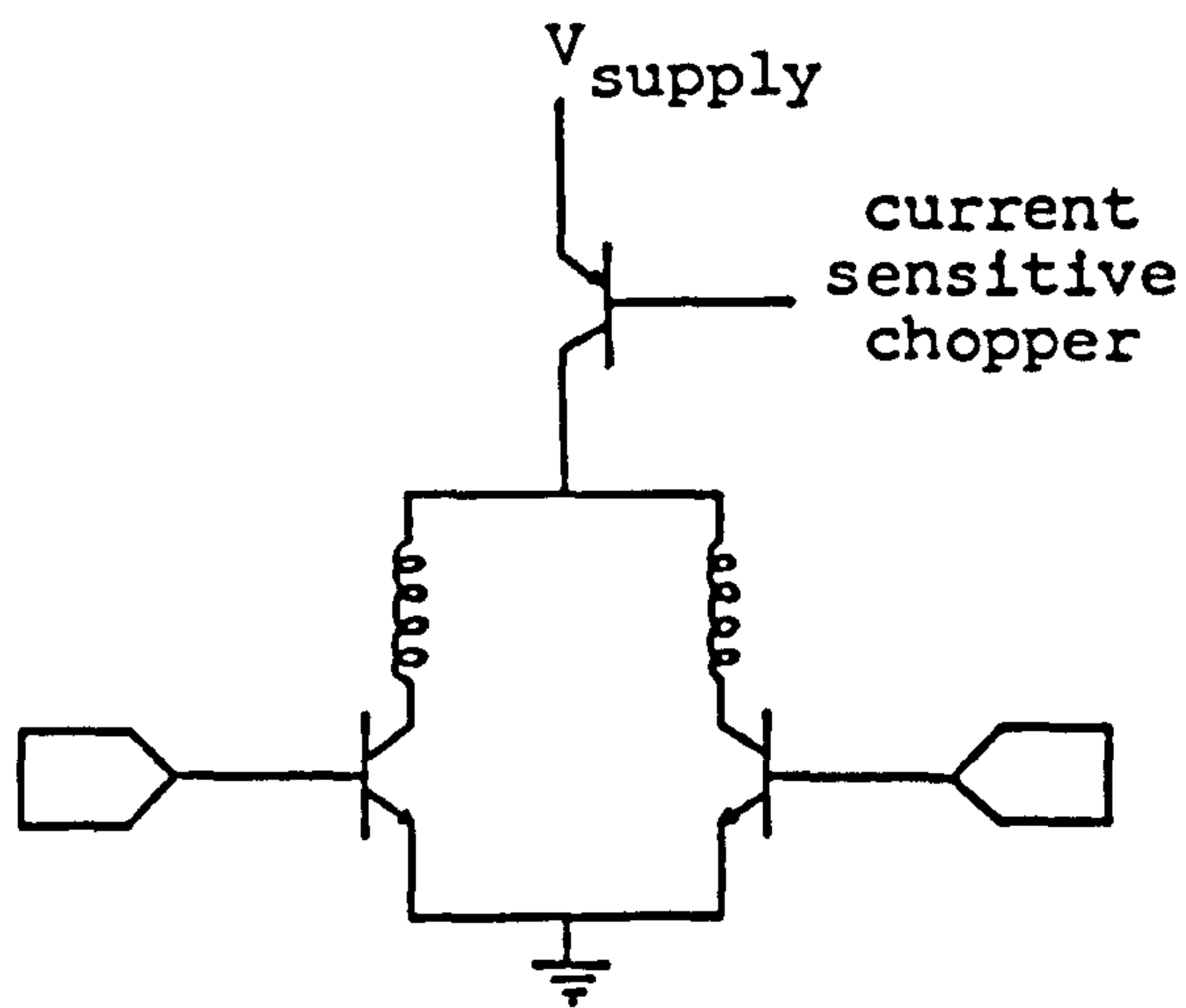


Figure 3.13 Current regulated chopper drive.

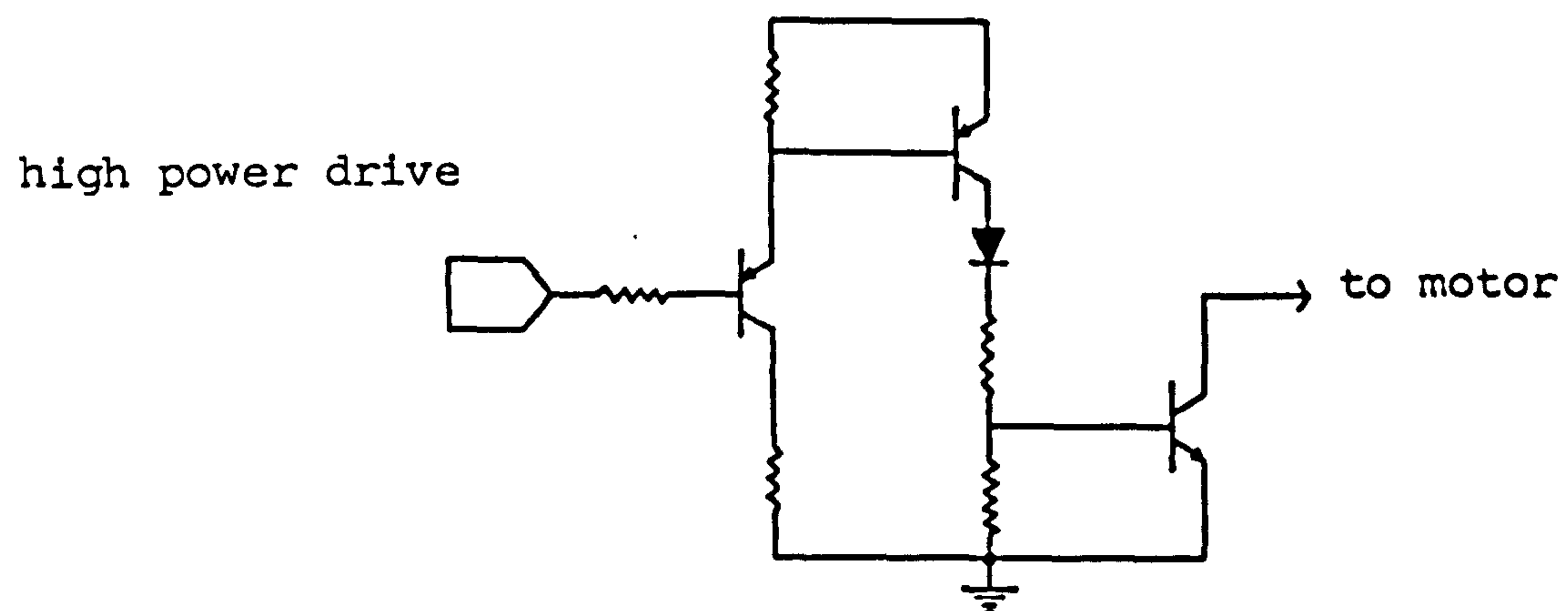
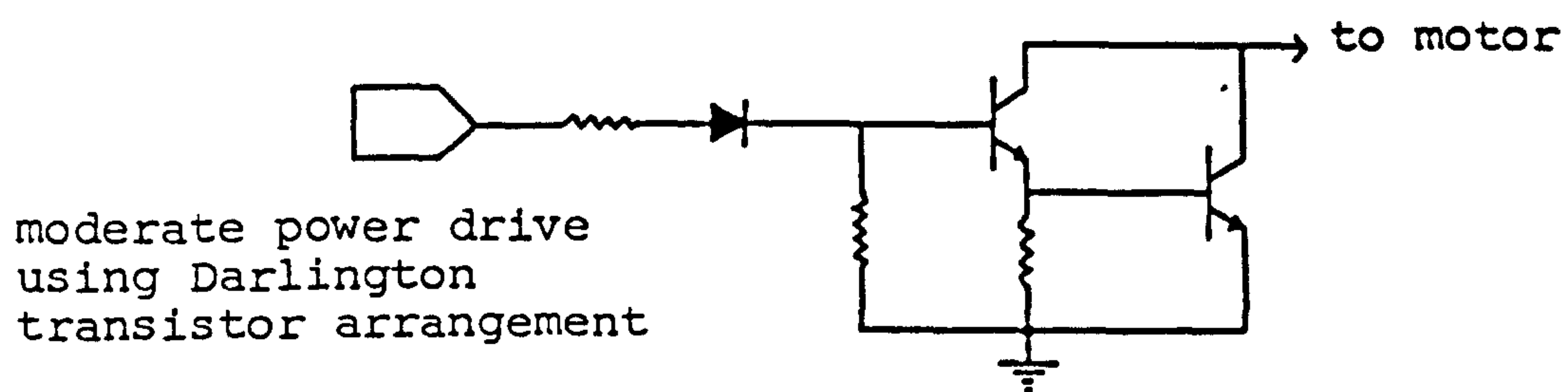
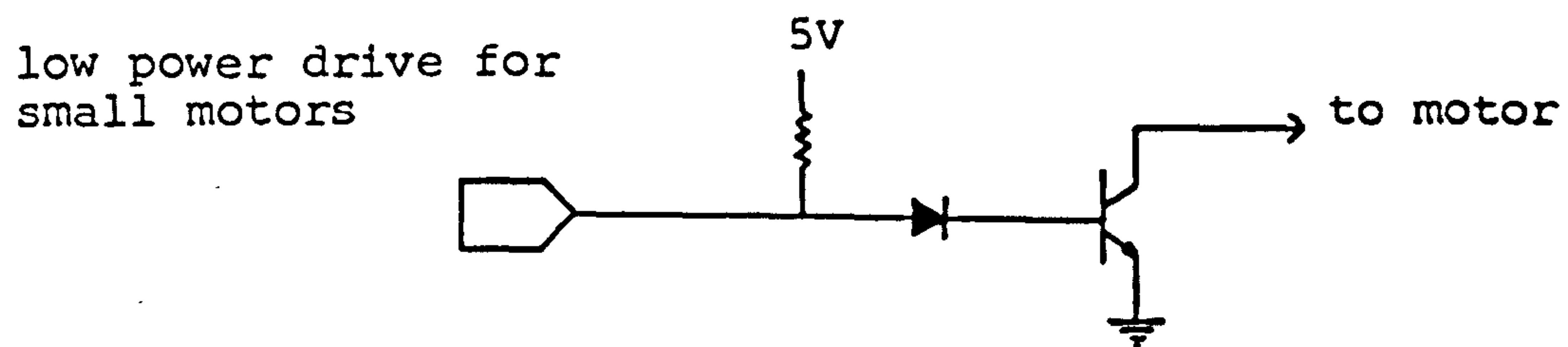


Figure 3.14 Switching circuits

drive is shown schematically in Figure 3.13. The chopper drive applies a high voltage at the beginning of each step, but prevents the current from exceeding its rated value by sensing and "chopping" it at a rate of approximately 4 kHz. This drive produces increased high speed performance and efficient power usage. Again no limiting resistors or related heat dissipating devices are required but component complexity and cost are increased.

3.2.5 Transistor Selection

The choice of transistors^{171,177} for any of these switching applications is extremely important. Transistor switching time is the most critical factor. The longer the transistor takes to switch on or off the more power there will be to dissipate. Common switching times for power transistors are from 1 to 2 μs ^{178,179}. Any switching time of longer duration begins to waste power. An efficient switching transistor and an adequate protection network will help considerably to keep the transistor's temperature down. A heat sink must be used which is large enough to keep the transistor's junction temperature within the rating for all phases of operation. Most heat is created when the motor is stationary. Since the translation stage to prepare the switching signals is usually from low power sources such as a microprocessor or logic circuitry the switching arrangement must also be isolated so as to protect it from any transient effects due to the switching of the coils. It is best to keep the last of the selection at the lower power levels providing an output sufficient to drive the switching transistors. Figure 3.14 shows circuits for low, moderate and high power

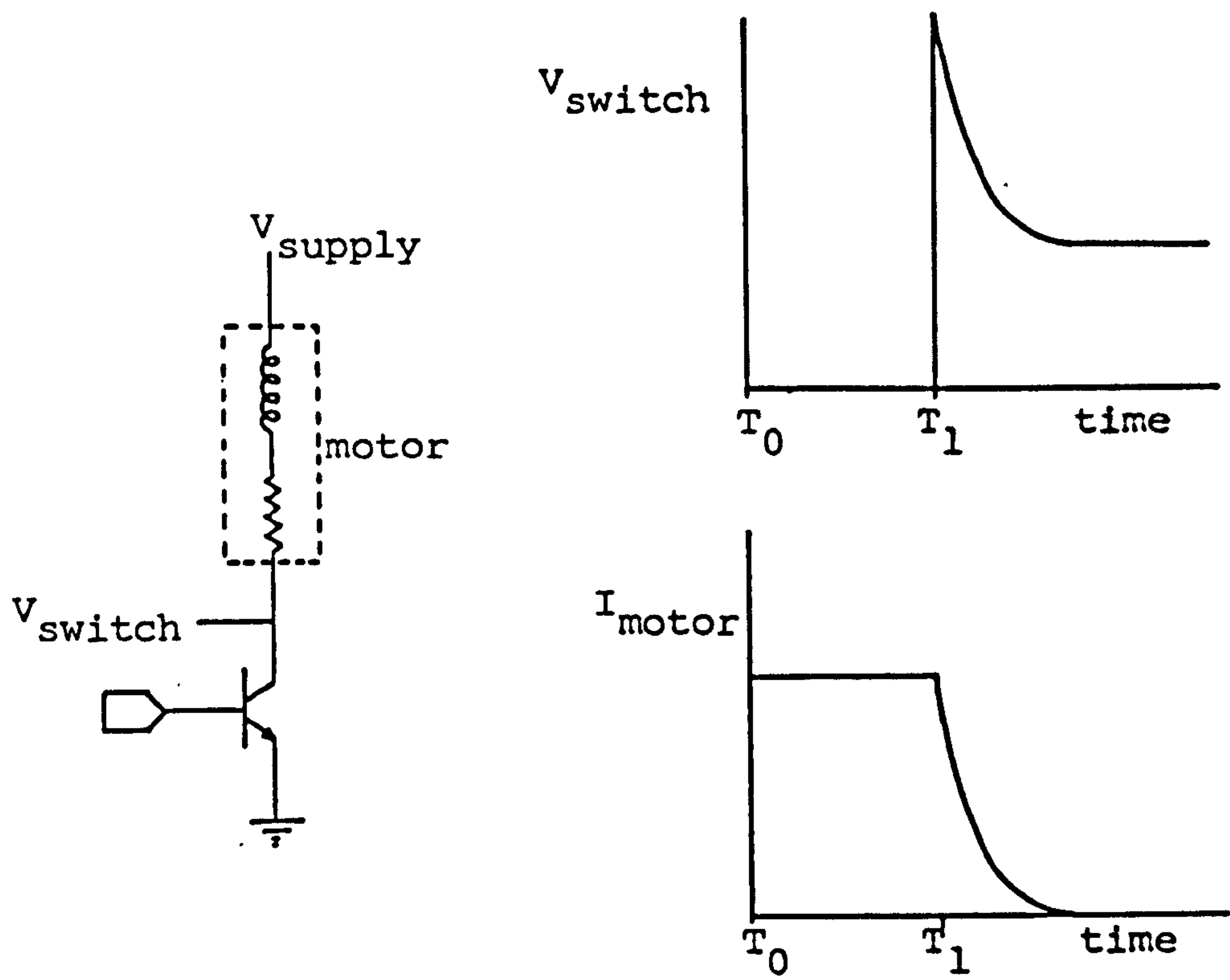


Figure 3.15 Effect of switching in the motor coil.

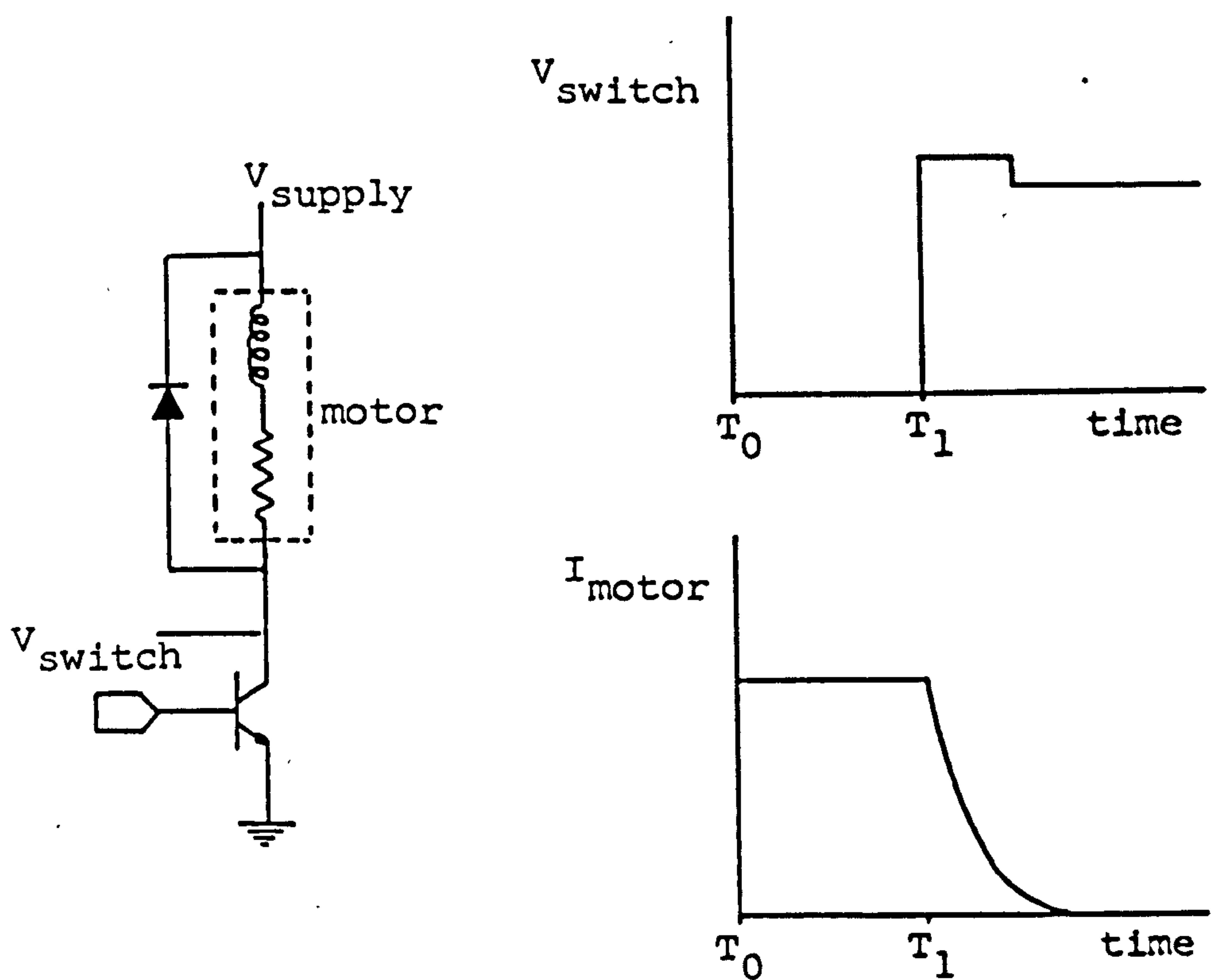


Figure 3.16 Effect of switching in the motor coil with diode protection.

drives. In the case of the bipolar drive, special care must be taken to ensure that the two transistors on one arm of the "H" are not turned on together, as explained in section 3.2.2.

3.2.6 Protection Circuits

It must be remembered that in all these cases the motor presents an inductive load and hence it is important to protect the transistors from high voltage and current transients in the system. The basic problems can be seen with reference to Figure 3.15. Initially T_0 , the switch (transistor), has been on for some time and current is flowing through the winding. At time T_1 the switch is opened. Because the winding is an inductor the current continues to flow for some time and the voltage instantly rises in order to maintain that flow. This transient voltage could easily knock out the transistor and hence must be limited to provide adequate protection.

3.2.6.1 Diode Protection

The simplest solution is to connect a diode across the motor coil as shown in Figure 3.16. This acts to limit the voltage transient by providing an alternative path back to the supply. The current will eventually die out. The maximum voltage at the transistor would only be one diode drop above the supply. If a resistor is added in series with the diode the time for the current to die away is reduced. This has advantages at higher speeds, making the recovery time shorter, though the voltage transient is increased to V_{supply} plus the drop over the diode and the resistor.

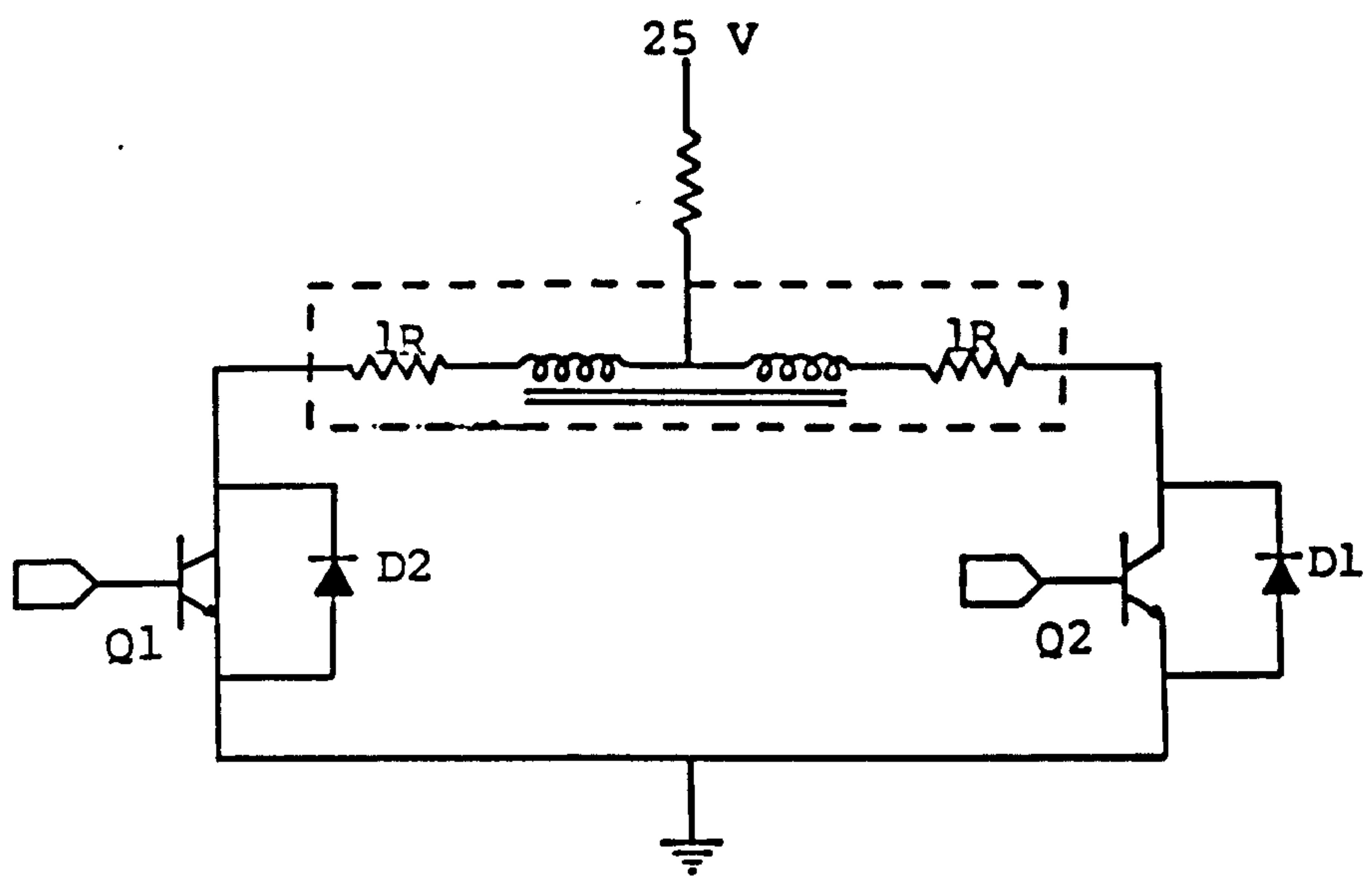


Figure 3.17 Bifilar suppression circuit connections.

Table 3.1

Comparison of stepper motors.

Sigma motor	20-2215 D200-E1.5	20-2220 D200-E5.1	20-2220 D200-E033	17-2220 D200-E033
Equivalents		MO61-FD02 FDS-/A51 astrosyn 23PMC004	MO61-FD02	
frame length (ins)	1.5	2.0	2.0	2.0
coil current still (A)	1.5	0.9	3.7	3.7
coil resistance at 20 C (ohms)	1.4	5.1	0.33	0.33
coil inductance (mH)	1.25	8.0	0.44	0.38
holding torque -unipolar (Nm)	0.19	0.42	0.42	0.36
detent torque (Nm)	0.010	0.020	0.020	0.017
rotor inertia (kgm ² x 0.0001)	0.006	0.013	0.012	0.006
<u>Unipolar drive performance at 24 V (12 V)</u>				
max. slewing (steps/s)	2600(1600)	800	4000	4000
max. stop-start (steps/s)	1200(1000)	700	1200	1000
power- 2 coils energised (W)	72(36)	38	180	180
max. torque (Nm)	0.15(0.18)	0.35	0.48	0.45
<u>Bipolar drive performance</u>				
- 20-222-D200-E5.1 and equivalents only				
drive voltage (V)	12	24	48	
max. slewing (steps/s)	800	1600	5000	
max. stop-start (steps/s)	750	850	1200	
power- 2 coils energised (W)	19	38	76	
max. torque (Nm)	0.55	0.60	0.65	

3.2.6.2 Suppression with Bifilar Wound Motors

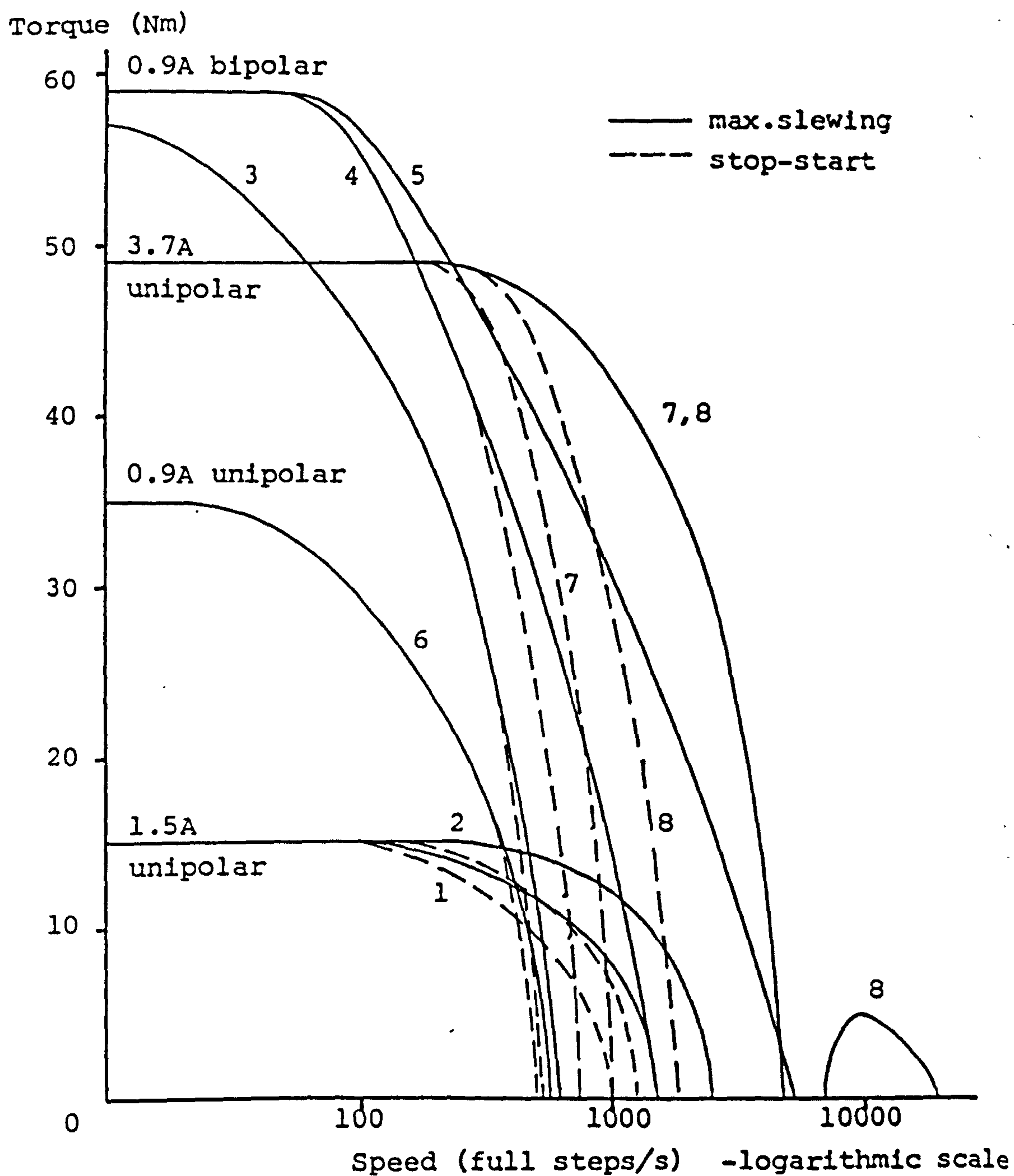
With a bifilar wound motor a different suppression circuit is possible. Here the other winding of the pole can be used like a transformer to discharge the current. Suppose the motor connected as shown in Figure 3.17 is carrying 5 A and transistor Q_1 shuts off. In order to keep the current flowing the motor finds a path from diode D_1 through the other winding and back to the supply. This however will affect the voltages. At first the winding connected to the diode D_1 is at -1 volt. When 5 A is flowing the motor common would be at 45 volts. When Q_1 switches off the voltage across it goes up to 95 volts as the windings act like a centre tapped transformer. The same thing will happen in the other winding when Q_2 is turned off.

Bearing this in mind the transistors should be chosen with ratings which can stand this as a reverse voltage over collector-emitter and collector-base junctions.

3.2.7 Comparison of Motor and Drive Combinations

One of the important considerations for the drive of yarn to a knitting machine is size. The drive unit must be kept as small as possible. For this reason the comparison has been limited to 2.2 inch diameter motors, which are the smallest high resolution motors available. Motors of two different lengths, 1.5 inch and 2 inch, are considered. All these motors are obviously small enough to be suitable for a high density drive situation. All motors will be discussed as the Sigma motors¹⁷² although Table 3.1 gives equivalents from other suppliers^{169,170}.

The 20-2215D200-E1.5 is the smallest motor and is driven



curve

1	1.5A	12V	unipolar	20-2215D200-E1.5
2	1.5A	24V	unipolar	20-2215D200-E1.5
3	0.9A	12V	bipolar	20-2220D200-E5.1
4	0.9A	24V	bipolar	20-2220D200-E5.1
5	0.9A	48V	bipolar	20-2220D200-E5.1
6	0.9A	24V	unipolar	20-2220D200-E5.1
7	3.7A	24V	unipolar	20-2220D200-E033
8	3.7A	24V	unipolar	17-2220D200-E033

Figure 3.18 Comparative motor performance.

with 1.5 A per phase. Figure 3.18 and Table 3.1 show the effect of changing the driver voltage for this motor. Here increasing the voltage from 12 to 24 V (curves 1 and 2) gives considerable improvement in maximum stepping rate but only a small change in stop-start rate. The change in maximum delivery torque is also very small but the electrical power to drive the motor is doubled. If the 20-2220D200-E5.1 motor is considered driving in a bipolar arrangement, it can be seen that an increase in driver voltage results in similar relative increases as for the unipolar drive (curves 3, 4 and 5). This type of motor, with the larger frame type, produces more torque even in the unipolar arrangement. Curve 6 shows the unipolar 24 V R/L drive for this motor which produces twice the maximum torque of the smaller frame motor but has much lower maximum stepping rates. The difference in stepping rates is due to lower current used to drive this motor: 0.9 A compared to 1.5 A.

The effect of higher currents for motors of the same frame size can be seen by comparing curves 6 and 7. Here the increase in current from 0.9 A to 3.7 A gives a considerable increase in both torque and maximum stepping rates.

Curves 4 and 6 are produced on the same motor for the same driver voltage and current but with 6 in the bipolar arrangement. It can be seen that bipolar drive gives approximately double the torque as well as offering higher stepping rates for the same electric power.

The difference between curves 7 and 8 is due to the inertia difference in the rotor between the series 20- and

17- motors under the same drive conditions. This results in a large improvement in the stop-start performance of the motor. The break in curve 8 represents a resonant range of the motor. By slewing (i.e. continuously changing step rates) through this range, steady state pulse rates can be used in the upper section of the curve.

More sophisticated drives such as the bipolar chopper offer considerable advantage in power saving but do not actually produce greater performance from the motor for a given driver voltage.

Within the course of this work three different drive combinations are used. The first uses the 20-2215D200-E1.5 with a unipolar 24 V R/L drive. This was chosen because of the small size of the motor and the simplicity and robustness of the unipolar drive. The second method uses the lower current (0.9 A) of the 20-2220D200-E5.1 motor but drives it with a 24 V bipolar R/L "H" drive. Because low currents are used, even with the increase in switching components, it still means that the cost of this drive is lower than a unipolar 1.5 A drive. The advantage here is primarily in reducing the power consumption for a given drive while using the more efficient driver to maintain performance. The third system, using a low inertia 17-2220D200-E033 motor, aims to get the highest acceleration from a system and may be necessary for the most demanding applications. Here again a 24 V unipolar R/L drive is used but here delivering 3.7 A per phase.

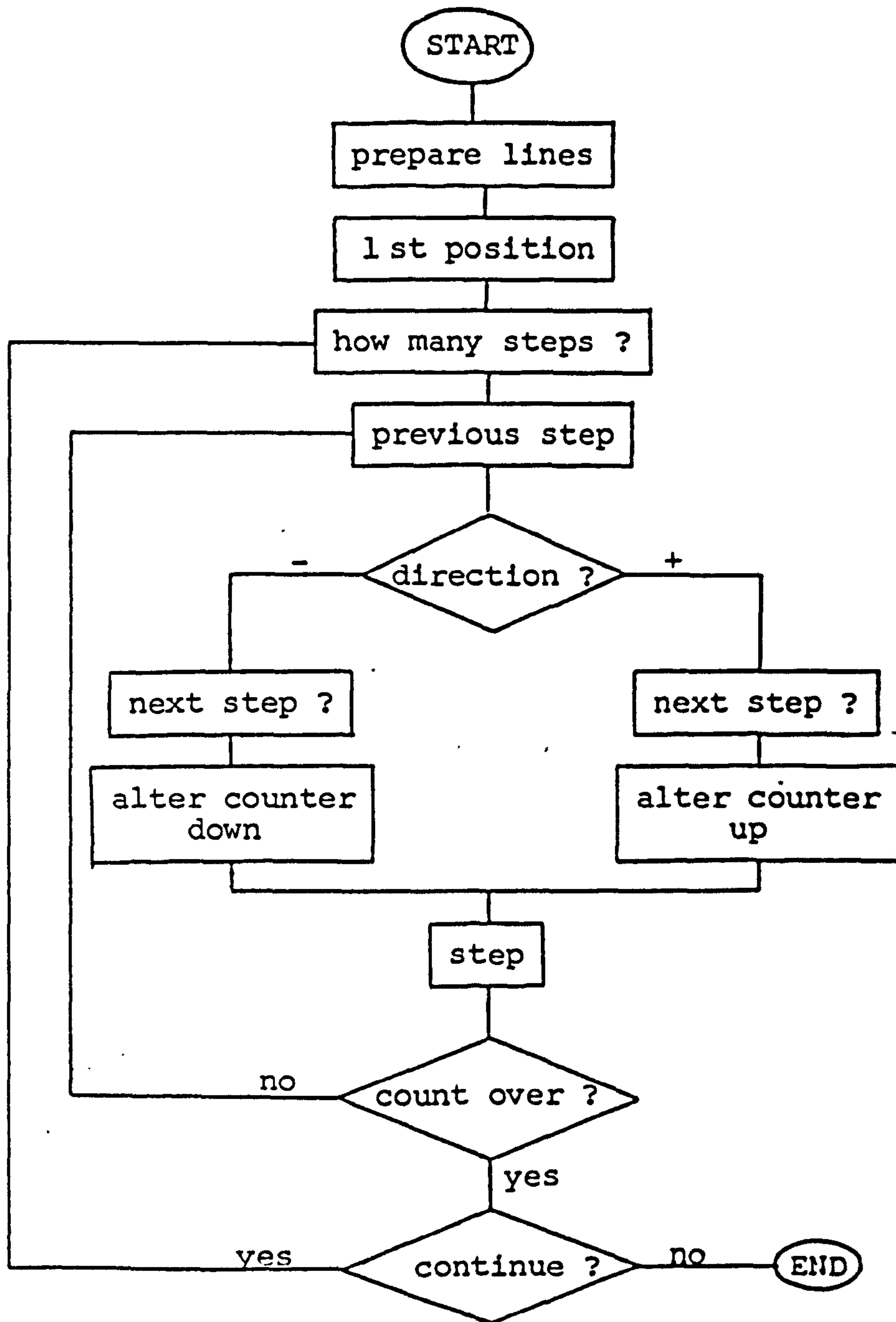
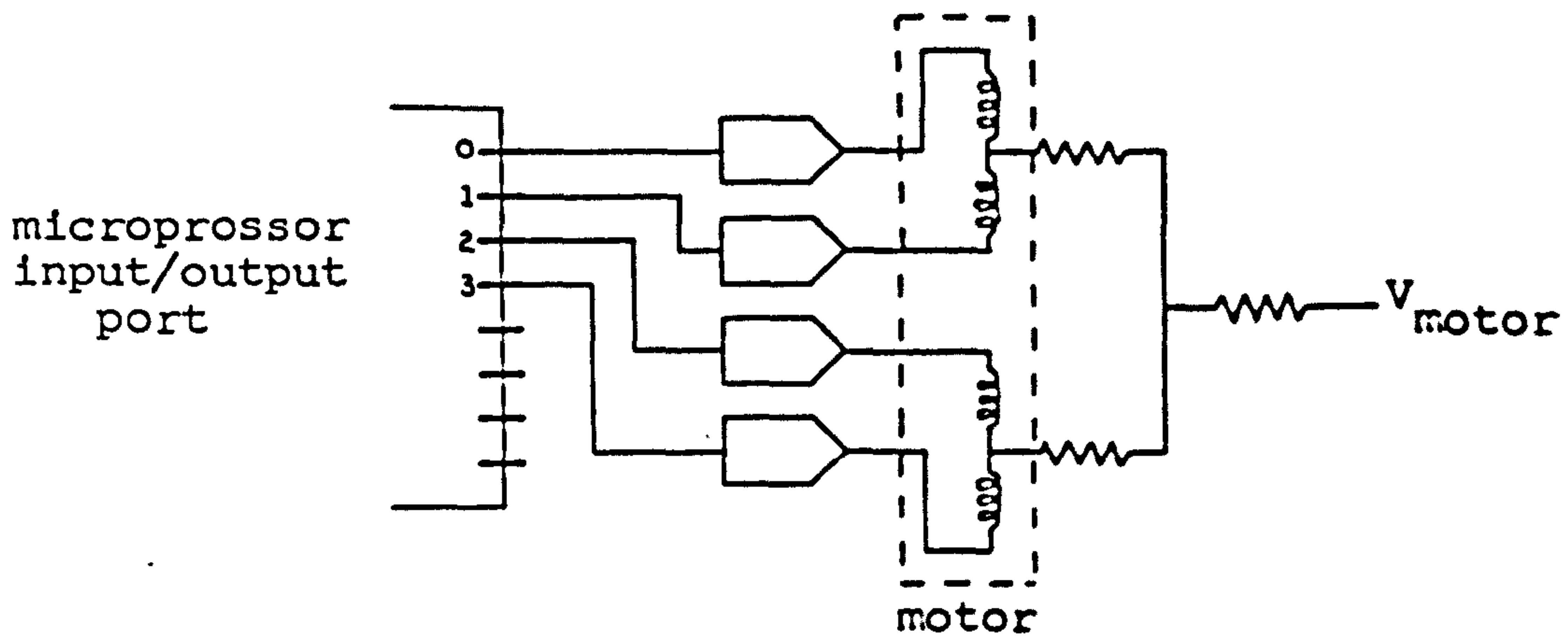


Figure 3.19 Microprocessor translation and step presentation showing connections and flow chart.

3.3 Generation of Stepping Sequences (Translation)

The logic to provide the switching sequences needed to drive a stepper motor can be derived from a microprocessor under software control or from a purpose built electronic hardware system. Both methods have advantages in different conditions. If the microprocessor is going to be used to carry out other functions connected with the running of the knitting machine it could be a reasonable choice but if the system needs to be cheap and easily duplicated, hardware would be more suitable.

3.3.1 Microprocessor Control

The four phase switching sequence usually required to drive one motor necessitates four output lines from the microprocessor. This is shown schematically in Figure 3.19.

The Commodore PET¹⁵⁴ is provided with an eight line input/output port with user selectable lines. Hence this could be used to drive two motors. If the program and control are carried out in Basic¹⁵⁵ software only the step commands need be presented to the output port. The port operates as a memory location and can be directly loaded. A flow chart for the required program is given in Figure 3.19 with a listing in Basic given in Appendix 14.

This system, though simple to operate, is drastically limited in speed. The interrupt cycle time of the Commodore PET is 1/60 of a second and so a motor could only be driven at 60 steps/s, even without the programming. This is well below the motor's performance capabilities.

By utilising a machine language program, however, the full speed potential of the motor can be utilised. Though

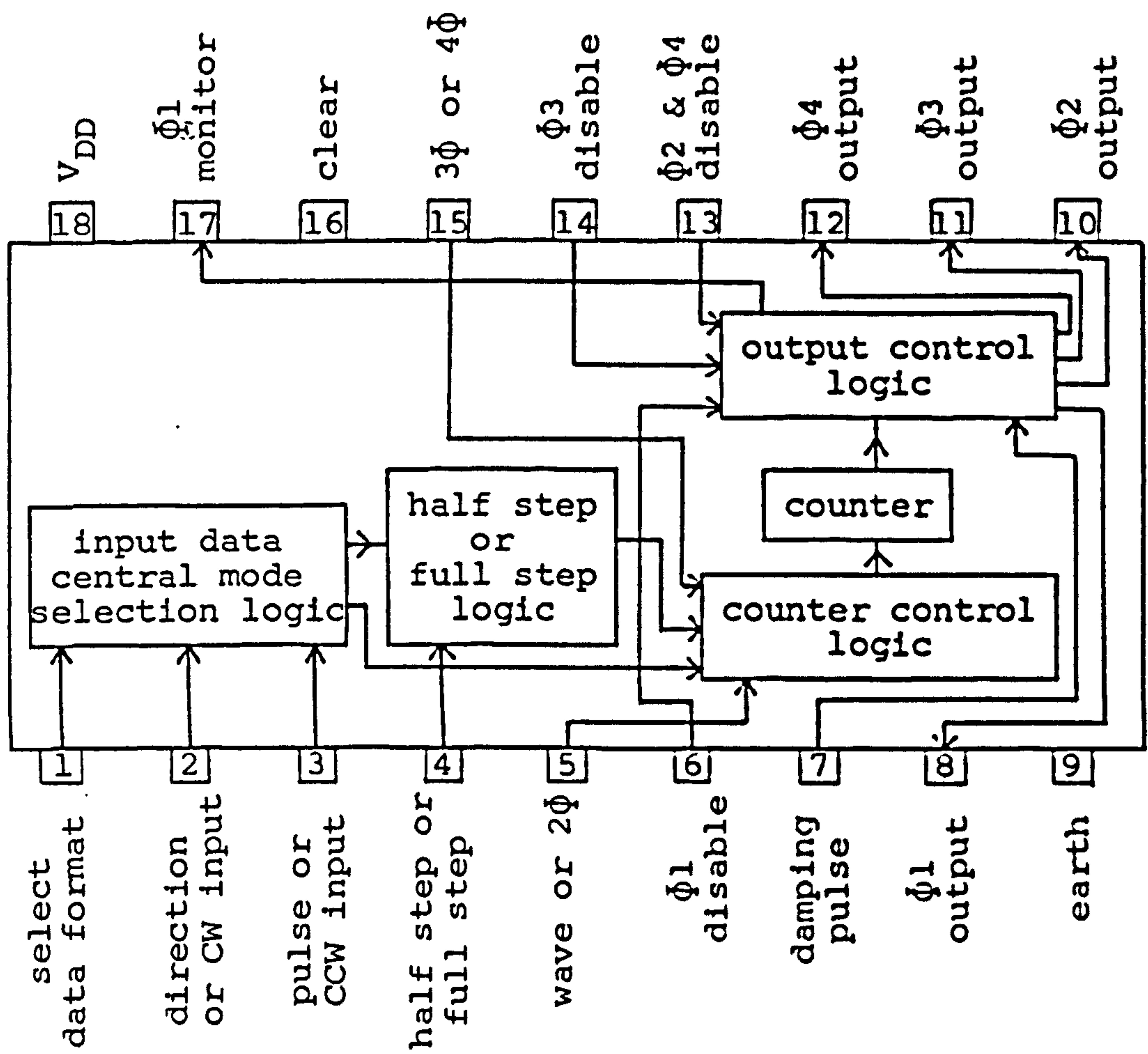


Figure 3.20 Digital Motor Logic (DML) circuit.

the programming is more complicated the same flow chart can be utilised. A listing for this is not given. As the motor can thus be operated extremely fast (the microprocessor clocking speed is 1 M cycles/s) it may be necessary to run the control in a closed loop situation to ensure maximum speeds are not exceeded. This can be achieved by using the edge sensitive input line of the PET to check if each step has taken place satisfactorily before the next step takes place.

In both these software systems all pulse requirements would be generated within the microprocessor. Without external logic circuitry a maximum of only two motors can be driven as only eight direct output lines are provided. Considerable versatility is however offered here, in that the motor stepping sequences can easily be changed from 200 steps/rev to 400 or even more. This is extremely important in accurate positioning systems. The motor may be quickly moved and then altered to microstepping for its final positioning.

3.3.2 Hardware Control

Hardware can also provide translation of a pulse train into the required stepping states. For this function it is possible to use purpose built logic circuit chips or build up a system from individual logic control components. Two purpose built circuits are commercially available: the DML¹⁸⁰ and the SAA 1027^{181,182}, which are both provided as single dual in line packages.

3.3.2.1 Digital Motor Logic Circuit (DML)

This CMOS^{183,184} chip schematically shown in Figure 3.20,

Table 3.2

DML functions and sequences

Input Data Modes

- Pin 1 = 1; pulse train and direction lines.
- Pin 1 = 0; CW pulse train and CCW pulse train.
- Pin 2 = 1; direction CW.
- Pin 2 = 0; direction CCW.
- Pin 3; pulse train input pattern changes on high to low transition.

Full Step Output States

Pins 1, 4, 6, 7, 13 and 14 = 0

C/R	30/40	Dir/CW	Pulse/CCW	Pin 5 = 0				Pin 5 = 1				Mon.
				φ4	φ3	φ2	φ1	φ4	φ3	φ2	φ1	
0	-	-	-	0	0	0	1	0	0	1	1	1
1	0	1	↓	0	0	1	0	0	1	1	0	0
1	0	1	↓	0	1	0	0	1	1	0	0	0
1	0	1	↓	1	0	0	0	1	0	0	1	0
1	0	1	↓	0	0	0	1	0	0	1	1	1

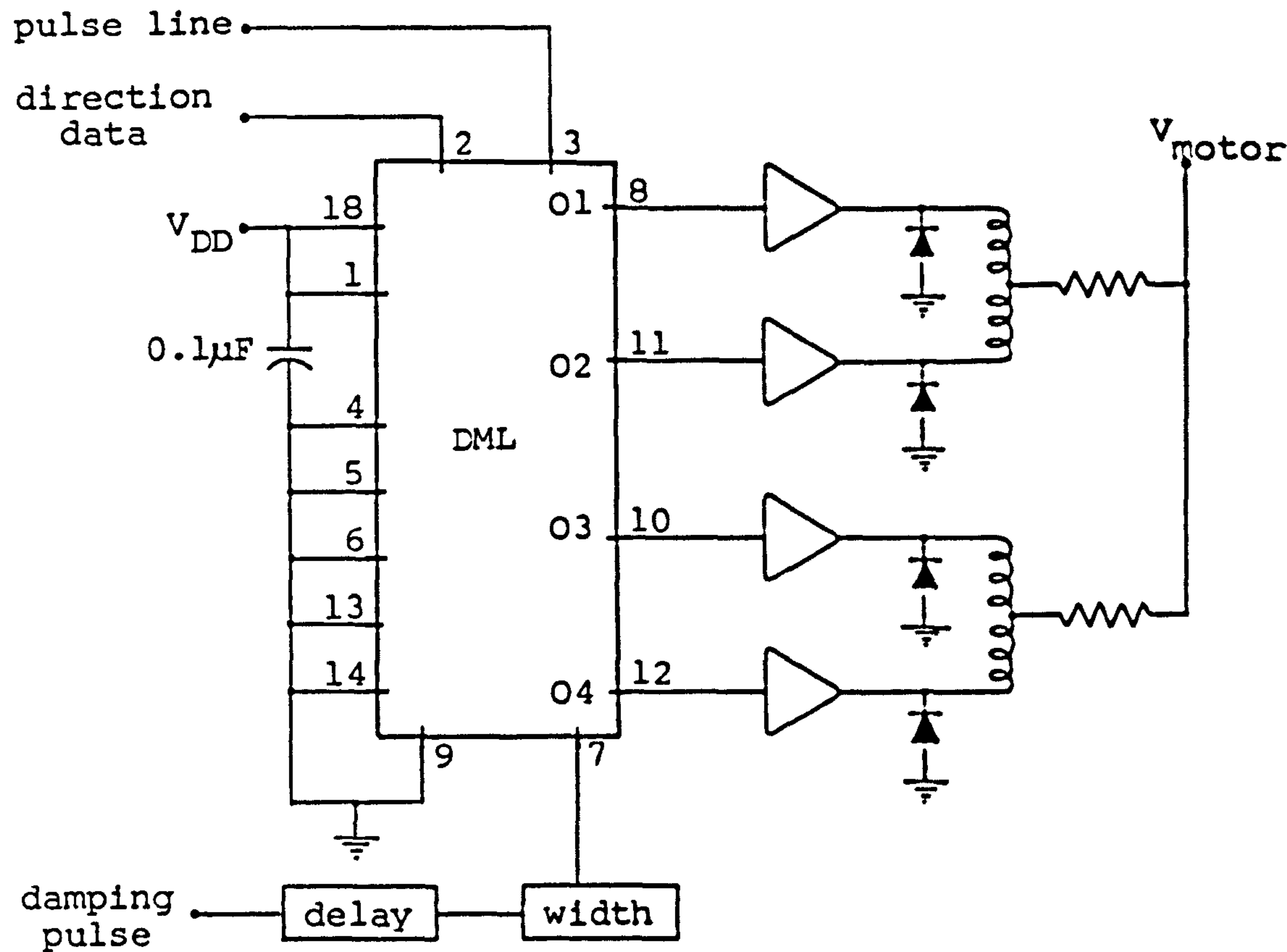


Figure 3.21 DML connections for a four phase full step drive with optional reverse pulse damping.

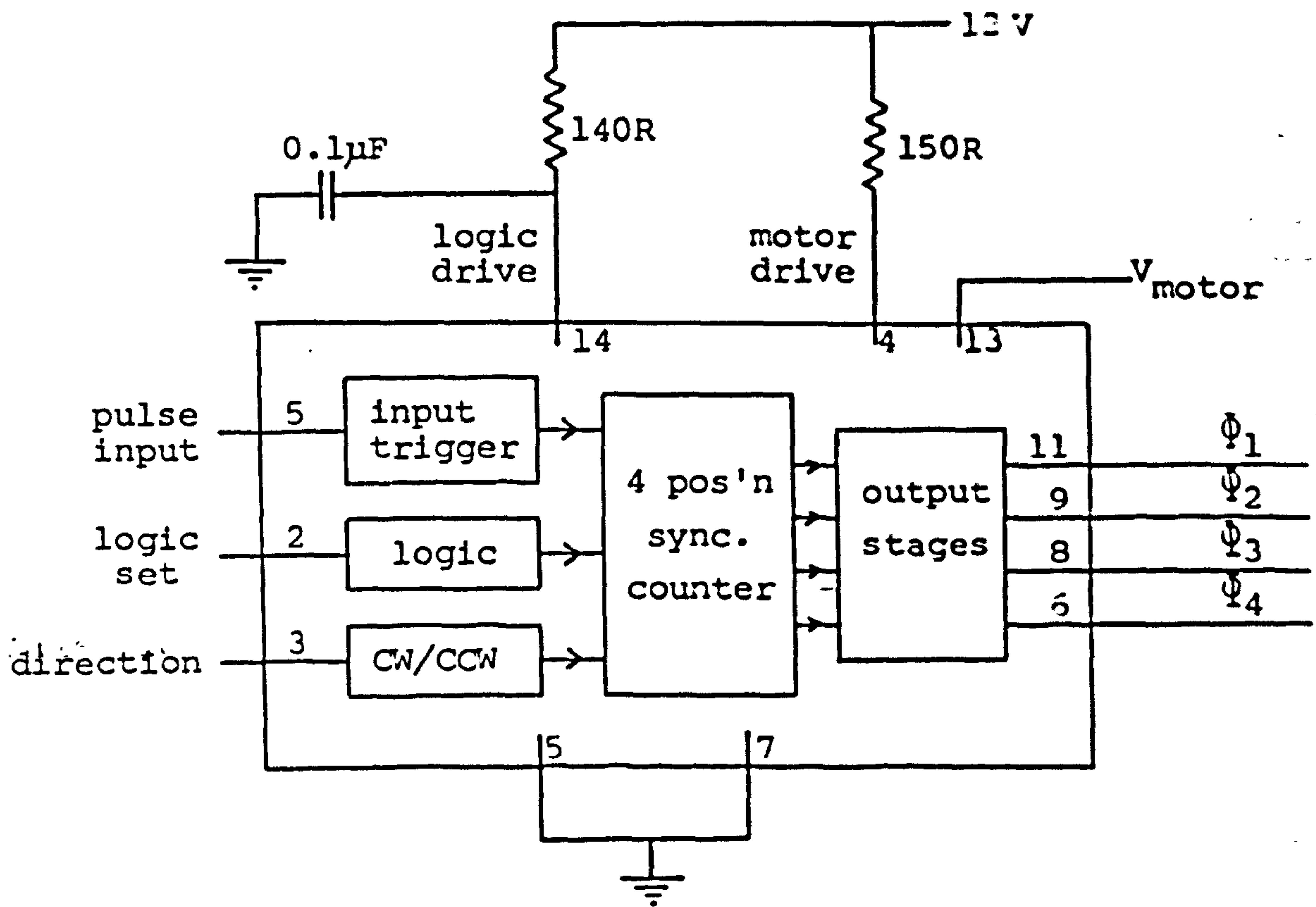


Figure 3.22 Schematic diagram of the SAA 1027 stepper motor drive circuit.

accepts a pulse train input and decodes it into a selectable parallel output stepper motor phase excitation format. The output states are generated at logic power levels. Sufficient flexibility is present in the chip to fit to most data input and output formats. The input can either be dual pulse trains for clockwise and counter clockwise rotation, or a pulse line and a direction line. The phase outputs can be two, three or four phase in either full or half step sequences. These are shown with the necessary control settings on Table 3.2.

Outputs can be in wave or overlapping sequences. The phase outputs can be selectively disabled for either standby power reduction or damping. There is a separate connection for a damping input. Connection for a four phase full step drive with optional reverse pulse damping is shown in Figure 3.21.

3.3.2.2 SAA 1027 Stepper Motor Drive Circuit

This four phase drive circuit is provided as a sixteen pin dual in line chip. Three inputs are provided for stepping input, logic set control and a direction control. The output can deliver 350 mA per phase and is diode protected. Thus it can be used to directly drive a low power motor, or can be further amplified for driving at a higher current. This chip is shown schematically in Figure 3.22.

3.3.2.3 CMOS and TTL Circuits

While both the purpose built chips are extremely versatile, they are expensive compared with standard logic arrangements which can also produce the stepping requirements.

The choice in standard logic is between the two major groups available: CMOS and TTL¹⁸³⁻¹⁸⁵. TTL has been chosen

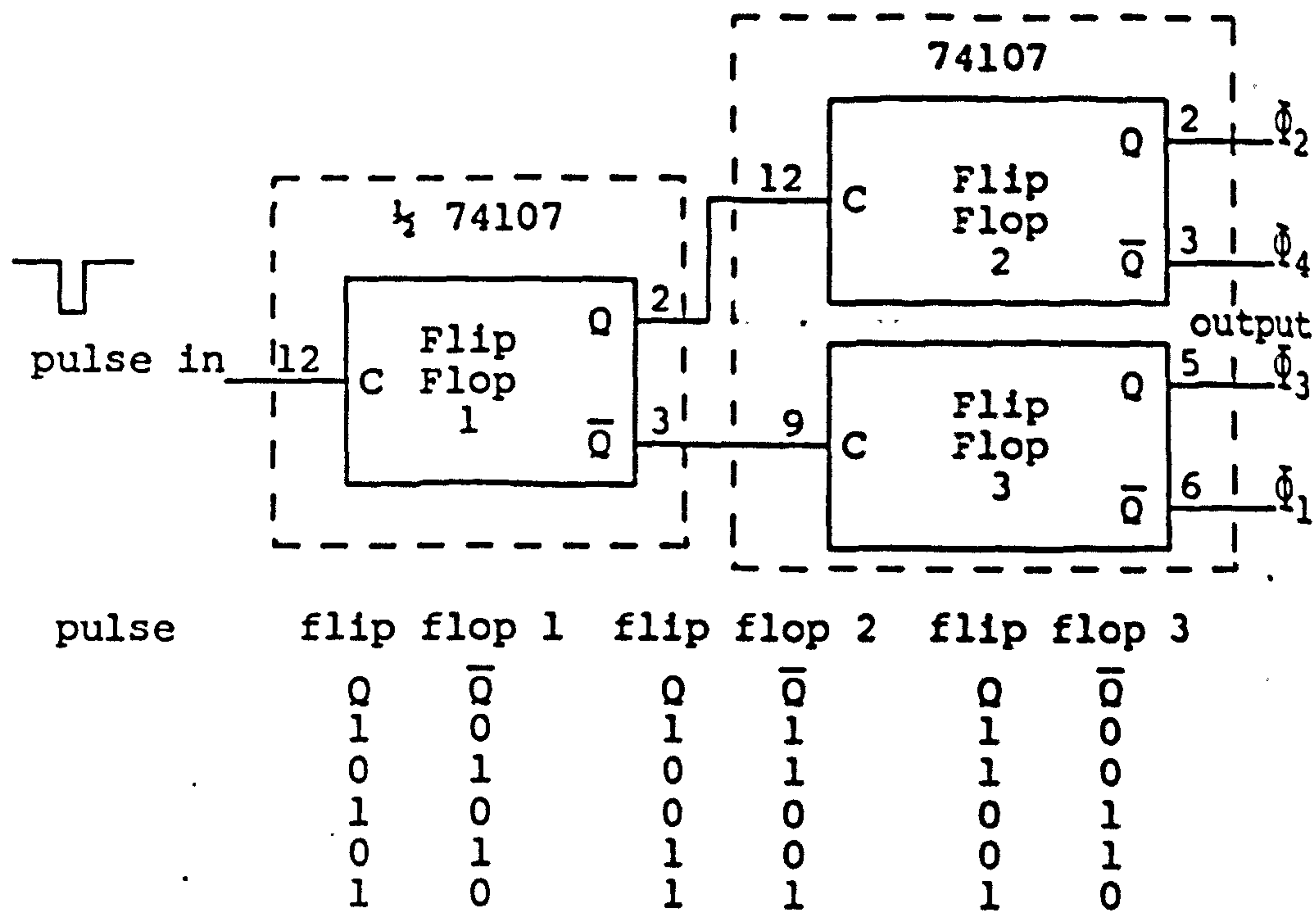


Figure 3.23 Three flip flops used to give full step sequence.

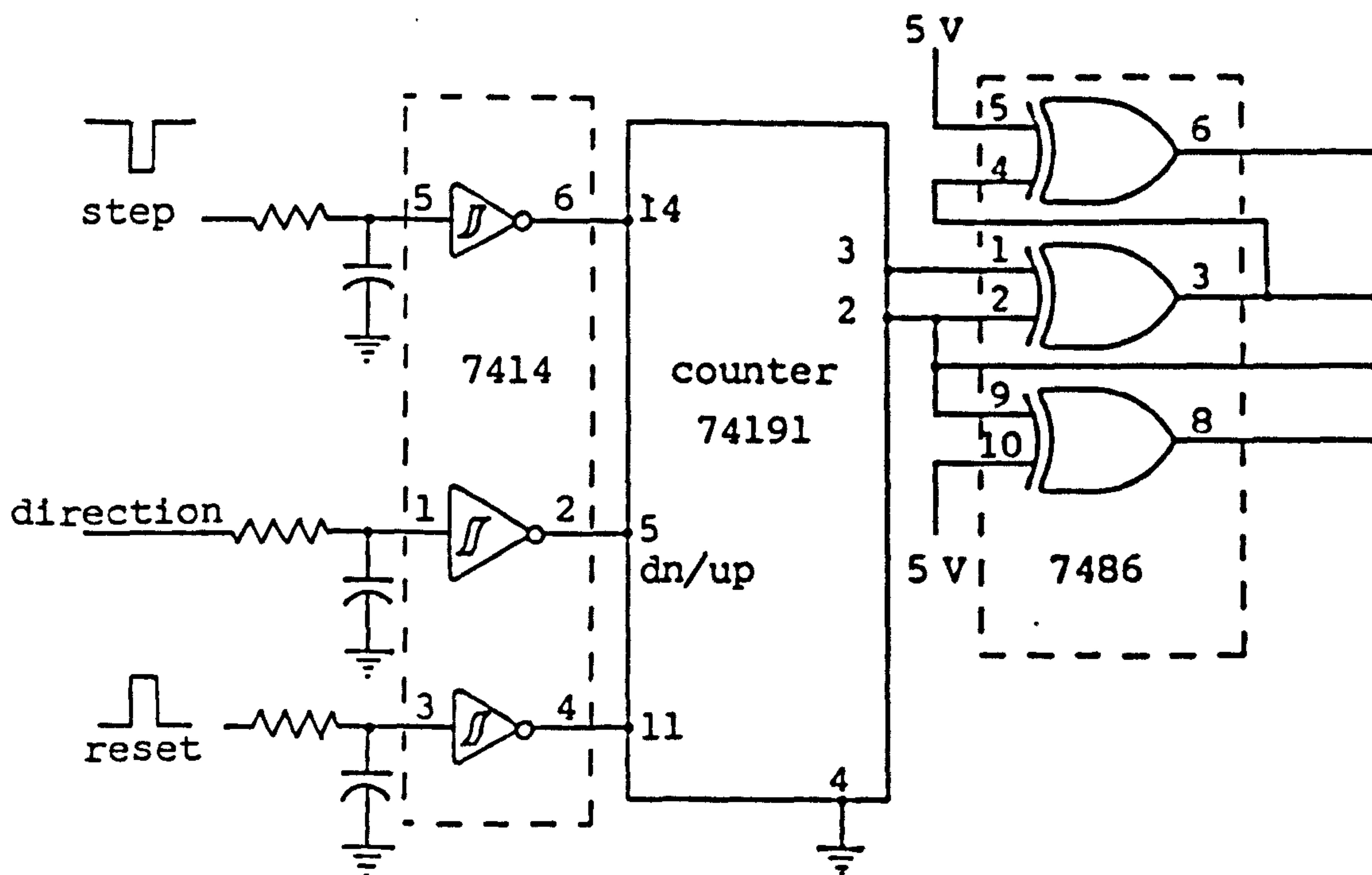


Figure 3.24 Translation based on an UP/DOWN counter.

Truth Table								
dec.	counter (step)				output step sequence			
	2^0	2^1	2^2	2^3	A	B	C	D
0	0	0	0	0	1	0	0	1
1	1	0	0	0	0	0	0	1
2	0	1	0	0	1	0	0	0
3	1	1	0	0	0	0	0	0
4	0	0	1	0	1	0	1	0
5	1	0	1	0	1	0	0	0
6	0	1	1	0	0	0	1	0
7	1	1	1	0	0	0	0	0
8	0	0	0	1	0	1	1	0
9	1	0	0	1	0	0	1	0
10	0	1	0	1	0	1	0	0
11	1	1	0	1	0	0	0	0
12	0	0	1	1	0	1	0	1
13	1	0	1	1	0	1	0	0
14	0	1	1	1	0	0	0	1
15	1	1	1	1	0	0	0	0

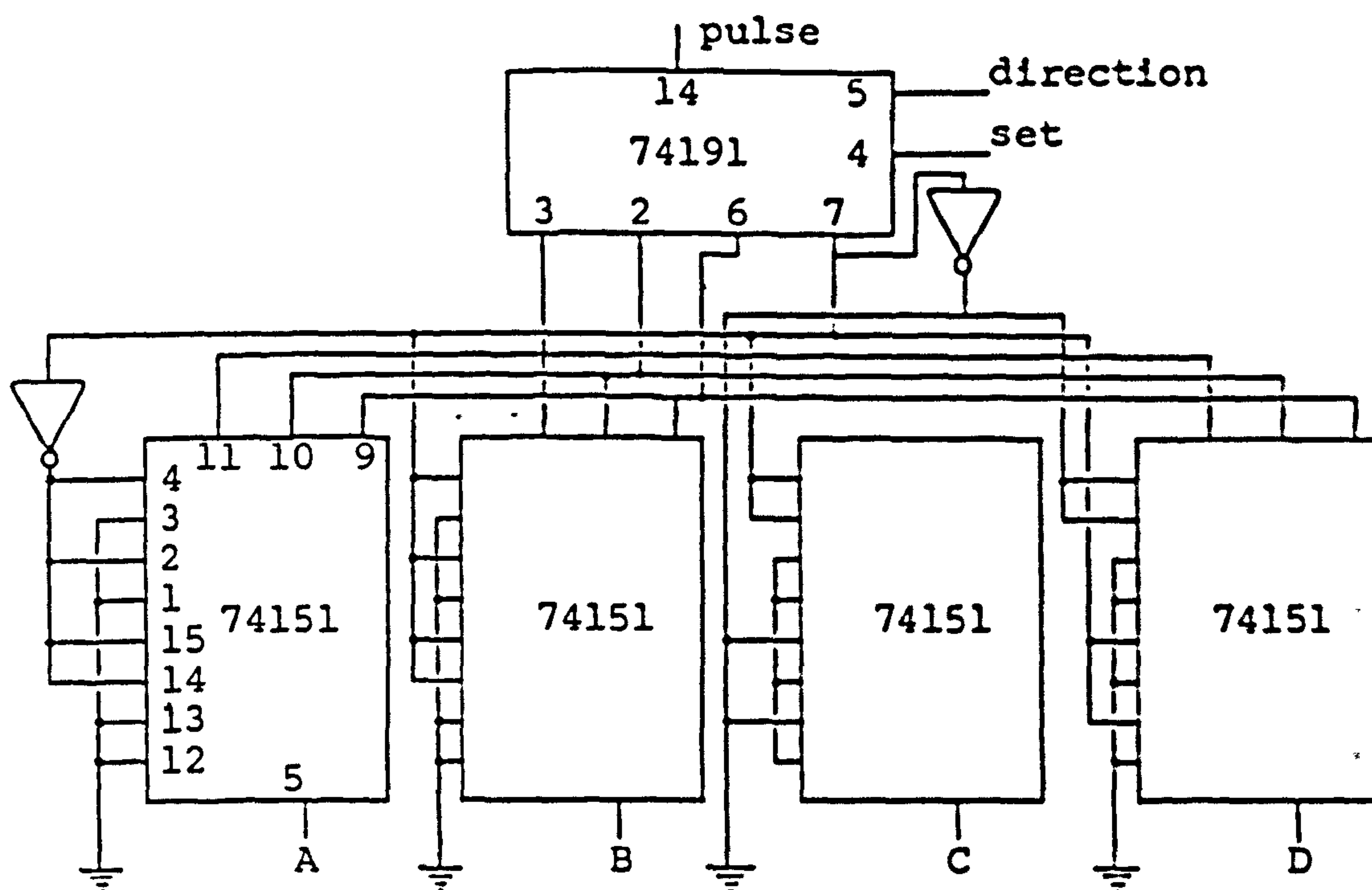


Figure 3.25 A 16 step sequence presented using data selectors (74151) under control of a counter (74191).

for most of this work primarily because it is robust: a desirable feature in developmental work. It offers a very high gate speed but uses more power than the CMOS alternative. CMOS is more sensitive to static electric conditions and power supply fluctuations. In both systems similar functions are possible.

Perhaps the most simple system using the TTL logic building blocks¹⁸⁵ requires only three flip-flops. Here a four step (full step drive) sequence can be achieved as shown in Figure 3.23. This would probably also require an input buffer in practice and so could be produced using only three packages, two flip-flops being provided on a single chip. This system uses the first flip-flop to switch changes from one output pair to the other. To enable bidirectional control it is simpler to use a counter as the base.

A system using a 7414 inverter buffer with a 74191 synchronous UP/DOWN counter with output decoding provided through a 7486 exclusive-OR package¹⁸⁶⁻¹⁸⁸ is shown in Figure 3.24. This system can present the stepping sequence in either direction as shown. Only the first two bits of the counter are used as a control which could be produced by two flip-flops with a similar output configuration.

To produce more complicated stepping sequences more logic is required but it can still be easily based on counters and flip-flops.

To further increase flexibility data selectors can be used. A very versatile pre-settable system can be developed around a 1 of 8 data selector (74151). Here each step sequence can be individually set and any sixteen step sequence can be developed. The example shown in Figure 3.25

sets up a sixteen step situation from a given truth table. Here four 74151s are used; one for each phase, the control coming from a four bit synchronous counter (74191). While this offers an extremely versatile system, in most cases this versatility is not required. More than 200 or 400 steps per revolution with direction change would rarely be required. Direction change is also not generally needed in yarn movement.

As the stepping sequences can easily and cheaply be produced with standard logic it is unnecessary to tie up the output lines of the microprocessor on translation activities. Only a single pulse line is then required to control each motor.

3.4 Pulse Generation and Control

The type of pulse needed depends mainly upon the type of translation used. As for the translation, the source of the pulses can be hardware or software controlled. If standard logic (TTL or CMOS) is used the limitation on the pulse width is a minimum of about 50 μ s. The maximum pulse width in most cases will not be limited.

As discussed previously the stepper motor can be started instantaneously up to a certain speed. If the required drive range is less than this the pulse rate can be changed without danger of loss of control over the motor. For any speed greater than this the motor should be gradually accelerated from the pull-in region to the speed required and then decelerated back to this region before stopping.

As the motor is required to drive yarn into a knitting process and the rate of yarn requirements for a given situation are proportional to machine speed, the pulse train

could be derived from the knitting machine movement. Consider the single knit case if one pulse is delivered to the motor for each needle passing the feeder. As long as the step length equals the loop length requirements the feed system is complete. Here a needle detector is necessary as a pulse generator. This arrangement would have the advantage of locking the motor movement to the machine movement. In the special case of knitting a shaped garment panel the yarn requirements are related to the number of needles used on each course. Here stepping off the needles would be a very important technique.

Added complications arise if the needles are selected to knit or miss in some pattern arrangement. When no needle is selected and the machine is running, yarn is required equal to the machine movement. A system would be required in which a machine movement pulse train and a needle selection train are produced and the motor can be switched from one to the other. While driving off each needle with all needles selected the speed requirements would seem to be within the the pull-in range of the motor i.e. generally less than 1000 steps/s. Some single knit or interlock machines will go faster than this but here the ramping slopes generated by accelerating and decelerating the knitting machine should keep the rate of speed change within stepper motor capabilities. However, where pulses are added in to account for needle selections, this must be done in such a way as to give a smooth motor response if the pull-in range is exceeded. This would require further pulse control than just steps produced from the needles.

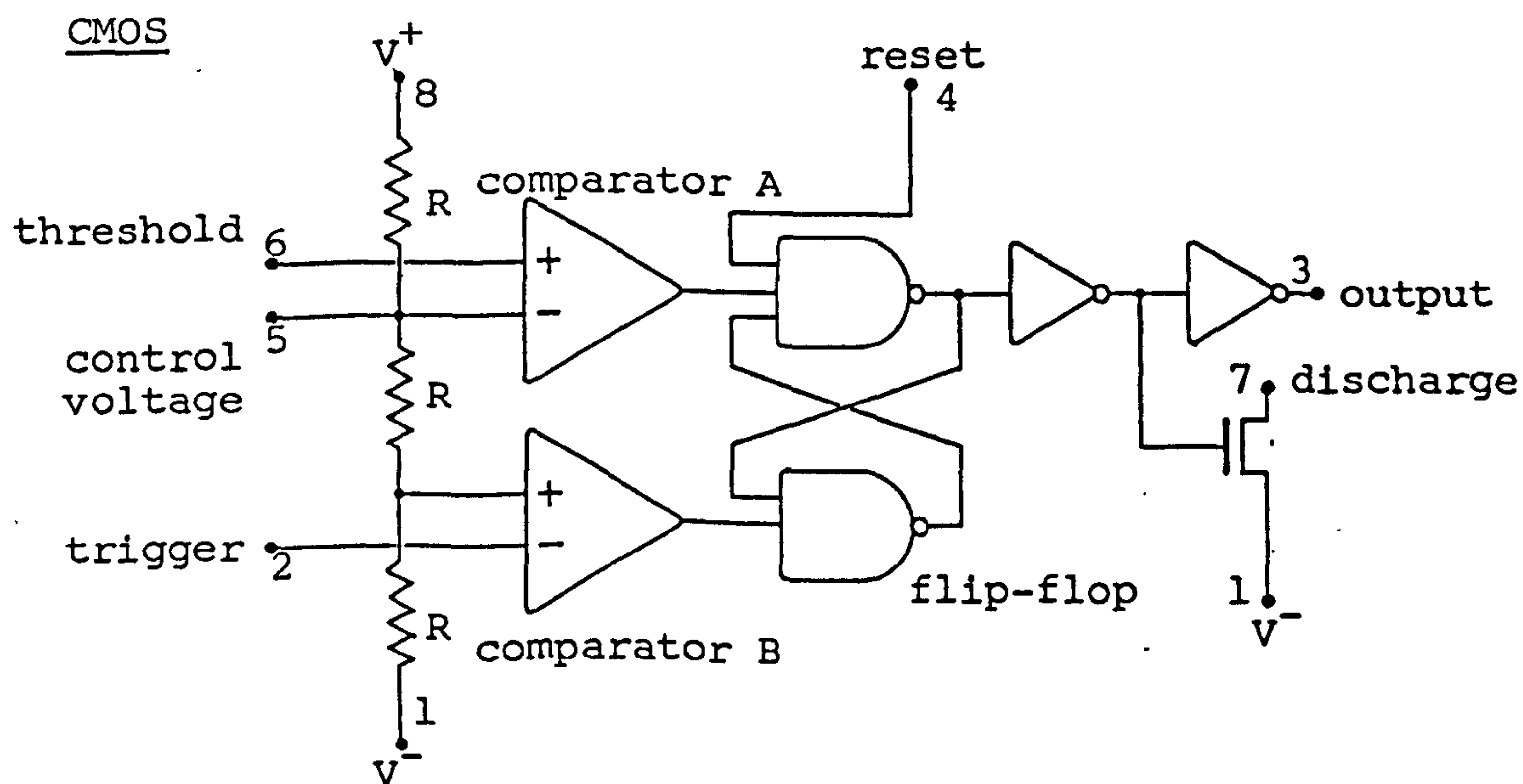
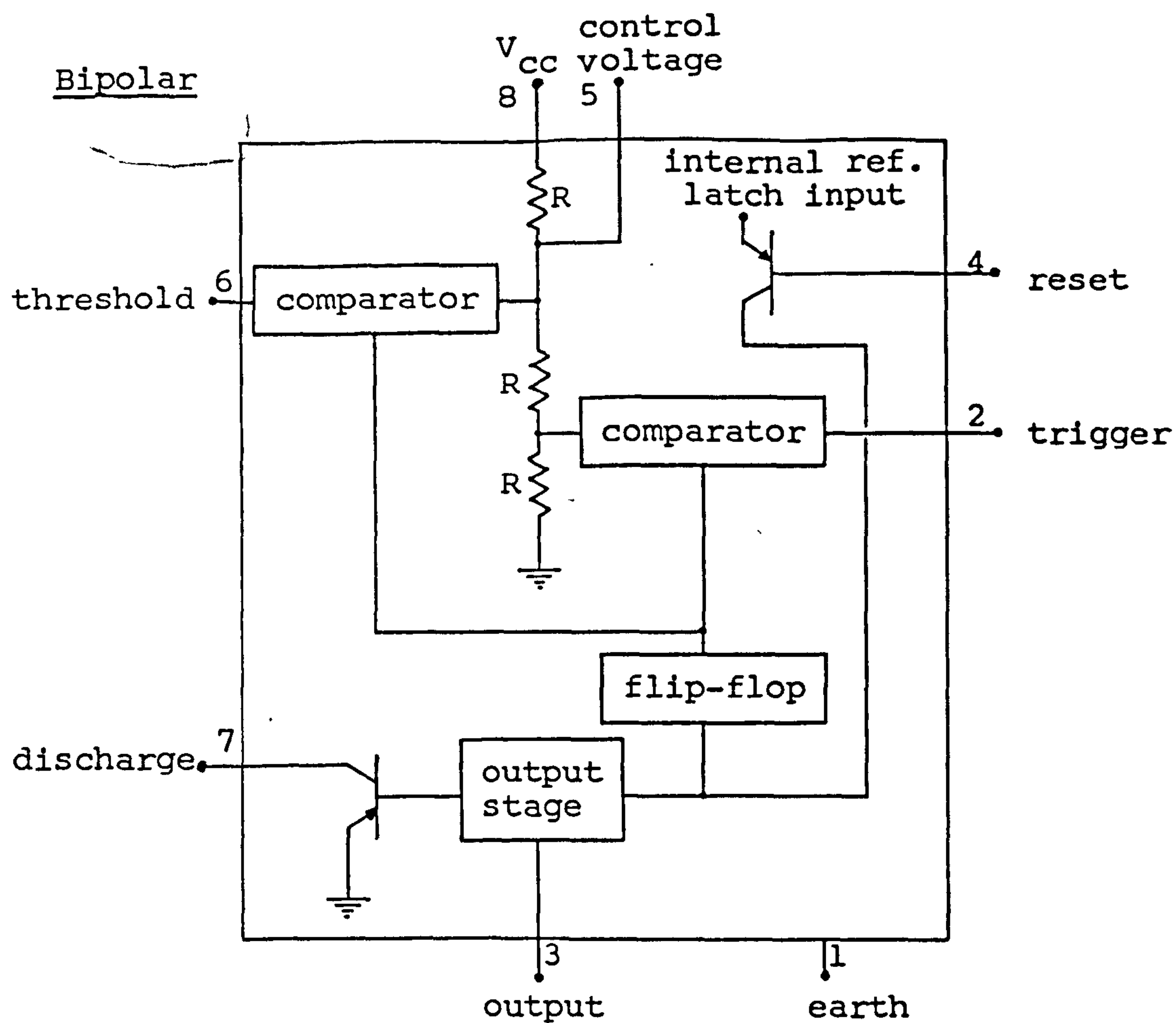


Figure 3.26 Schematic diagrams of the 555 in its bipolar and CMOS forms.

3.4.1 Oscillators

If the pulses to drive the motor are derived from an oscillator they must be compatible with the translation logic used. It would seem ideal to use oscillators based on components similar to the translation logic. Several integrated circuit timers exist¹⁸⁹. The most important of these are the 555 timer^{185,190} and the 2240 programmable timer¹⁹¹. The 555 is capable of running in both astable and monostable modes while the 2240 combines a time-base with a programmable eight bit counter from which a range of frequencies based on the pre-set oscillator can be derived.

3.4.1.1 555 Oscillator

The 555 chip is obtainable in either a bipolar or a CMOS form in eight terminal dual in line pin compatible packages. In the bipolar case it can be directly compatible with TTL (depending on drive voltages used) while the CMOS form is directly compatible with the CMOS logic family. Both of these forms of the circuit are shown schematically in Figure 3.26. A resistive voltage divider is used to provide references for upper and lower comparators of $2V_{CC}/3$ and $V_{CC}/3$ respectively. Control of the upper comparator is brought outside the package to allow external control of the timing period. Connections to control the 555 in a monostable mode are shown in Figure 3.27.

Here a pulse of length controlled by R_A and C is delivered at the output pin on a negative going edge of a trigger pulse. The length of this pulse is $1.1R_A C$ seconds (with C in farads and R_A in ohms).

To produce a continuous pulse train (astable operation)

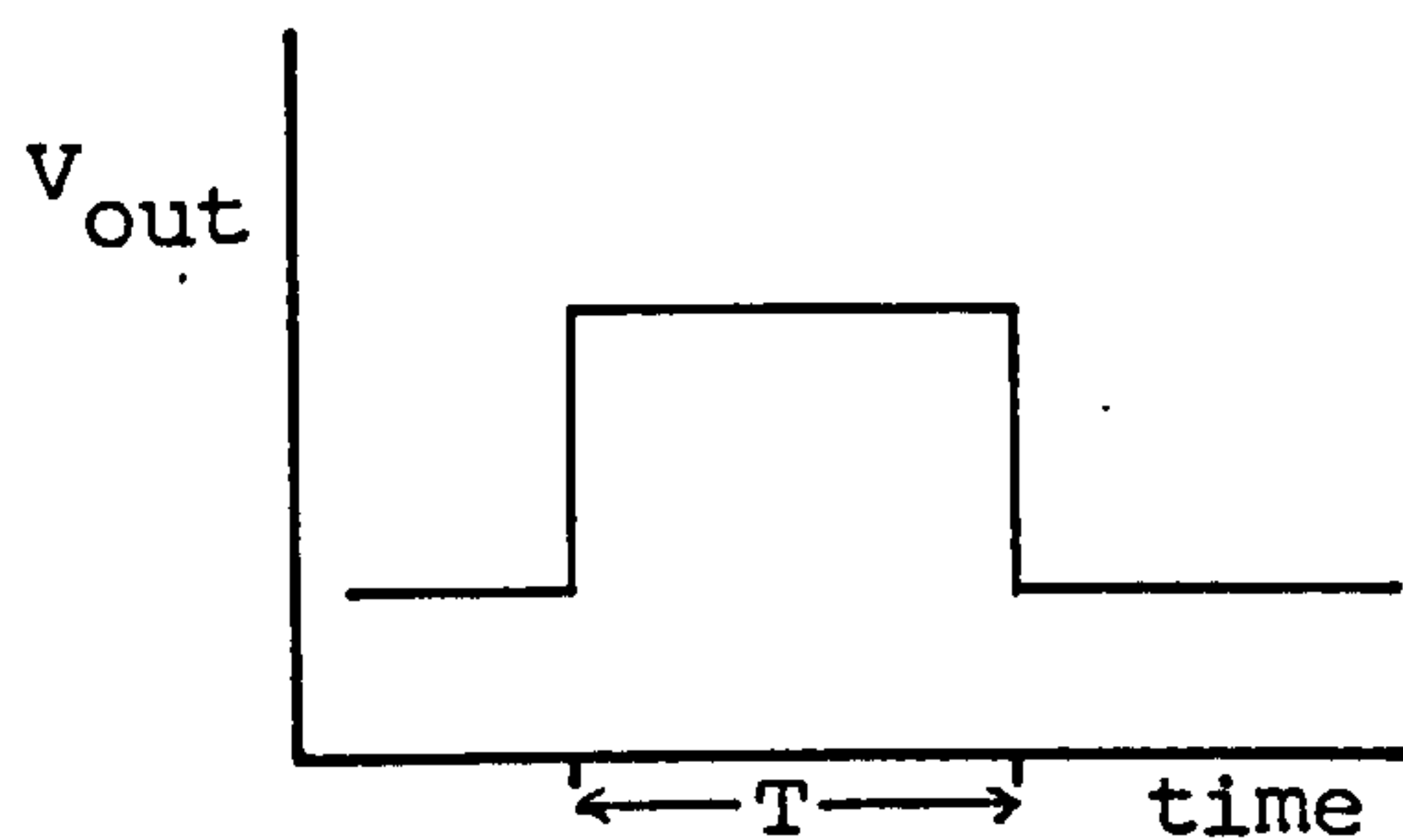
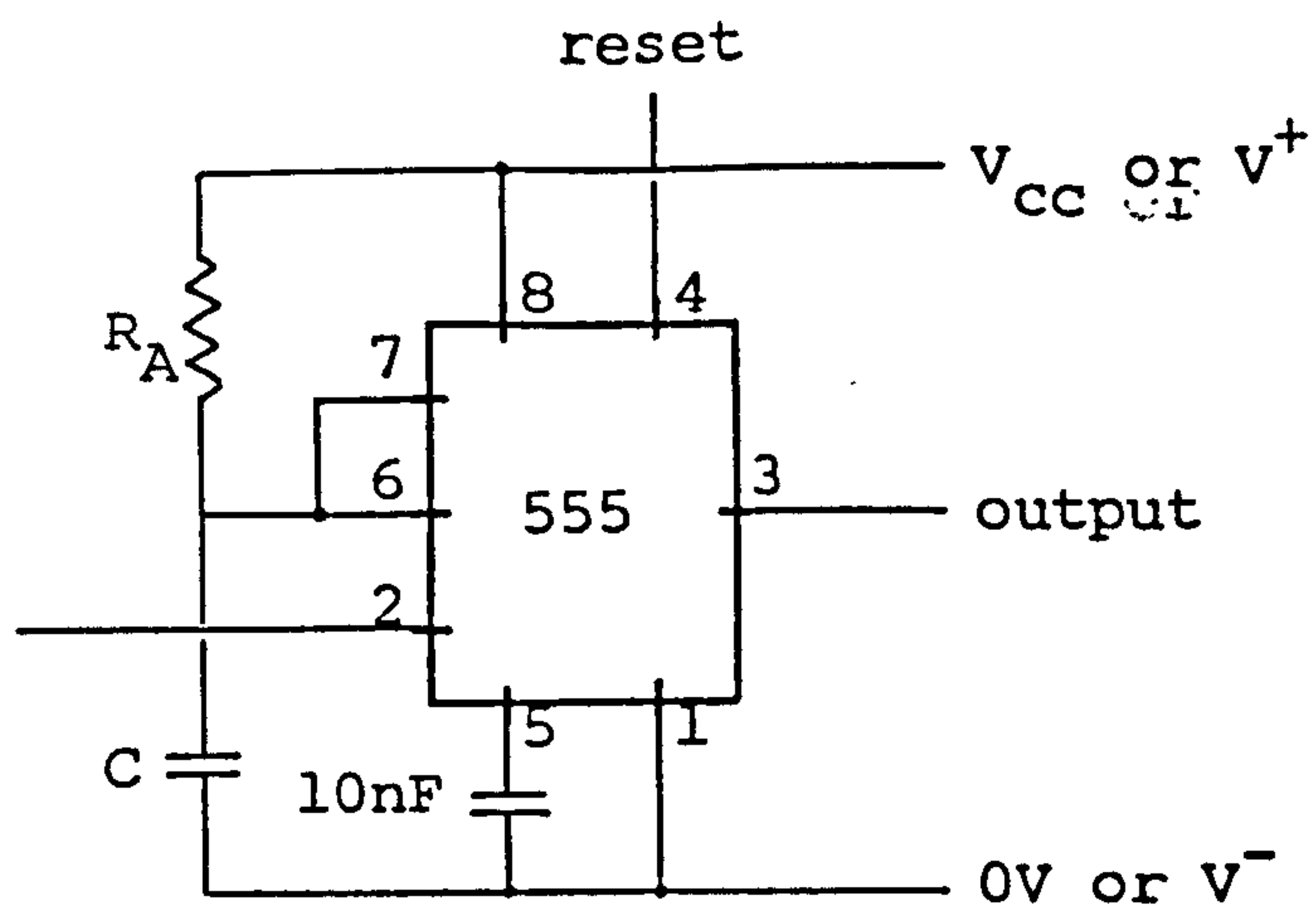


Figure 3.27 555 connected for monostable operation.

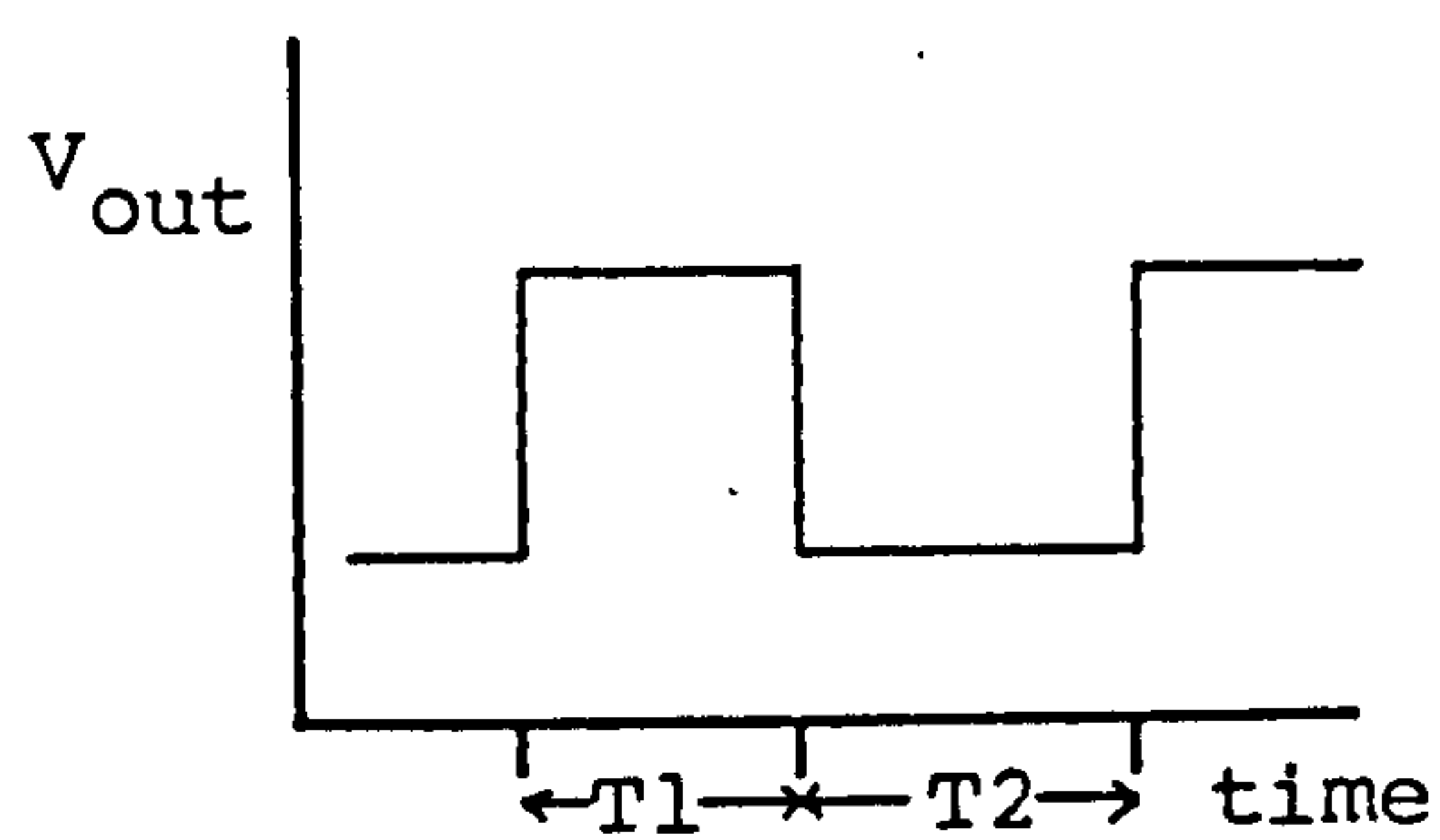
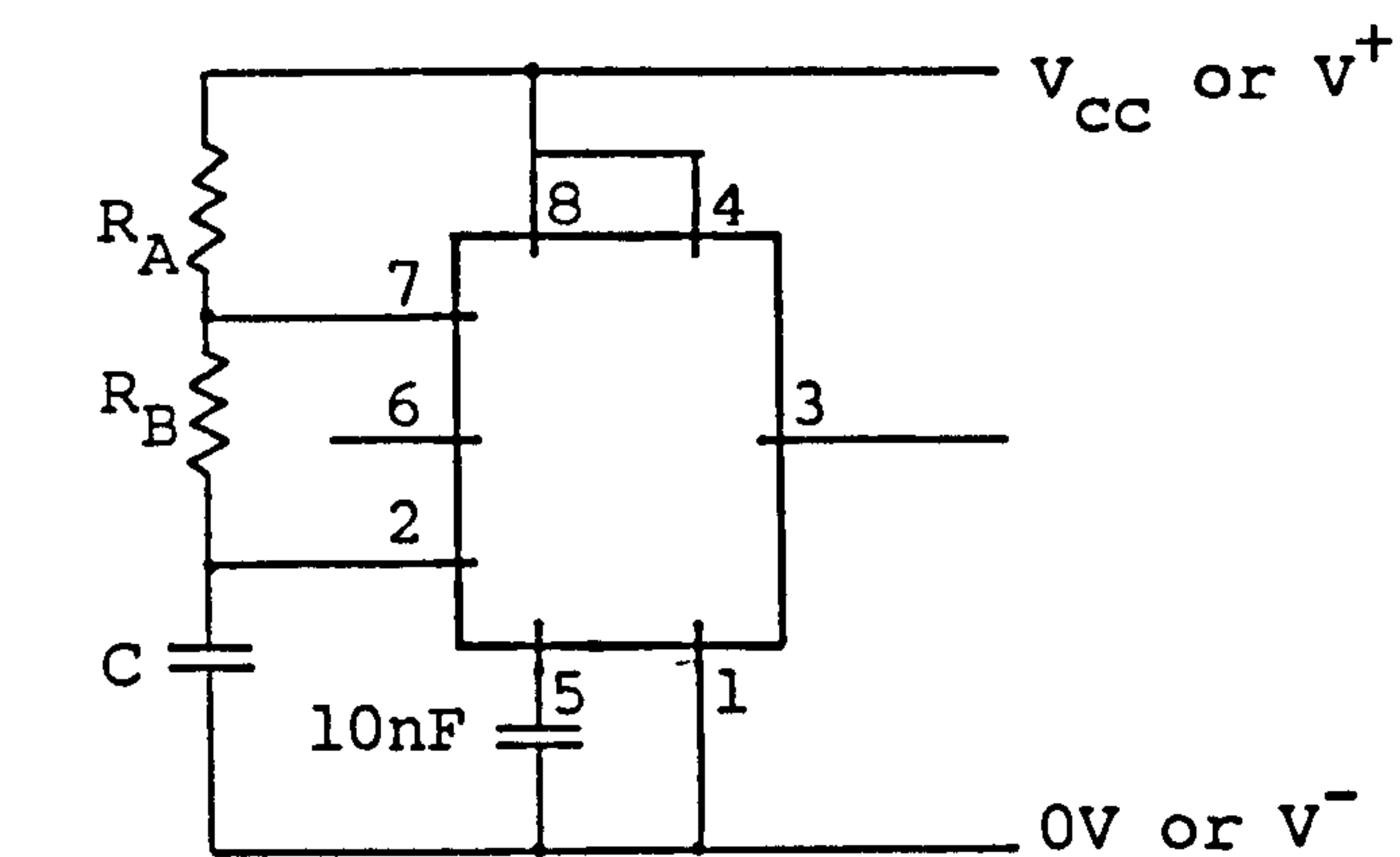


Figure 3.28 555 connected for astable operation.

the connections are as shown in Figure 3.28. Here an additional resistor is used and a pulse width $0.7(R_A + R_B)C$ seconds is produced at a spacing of $0.7R_B C$ seconds. Timer accuracy with these connections is typically 1% for the bipolar case and 2% for the CMOS¹⁹⁰. Drift with temperature is typically 20 ppm/°C while it is about 0.2% per volt with supply voltage. Thus the 555 provides a cheap and reliably functional pulse source.

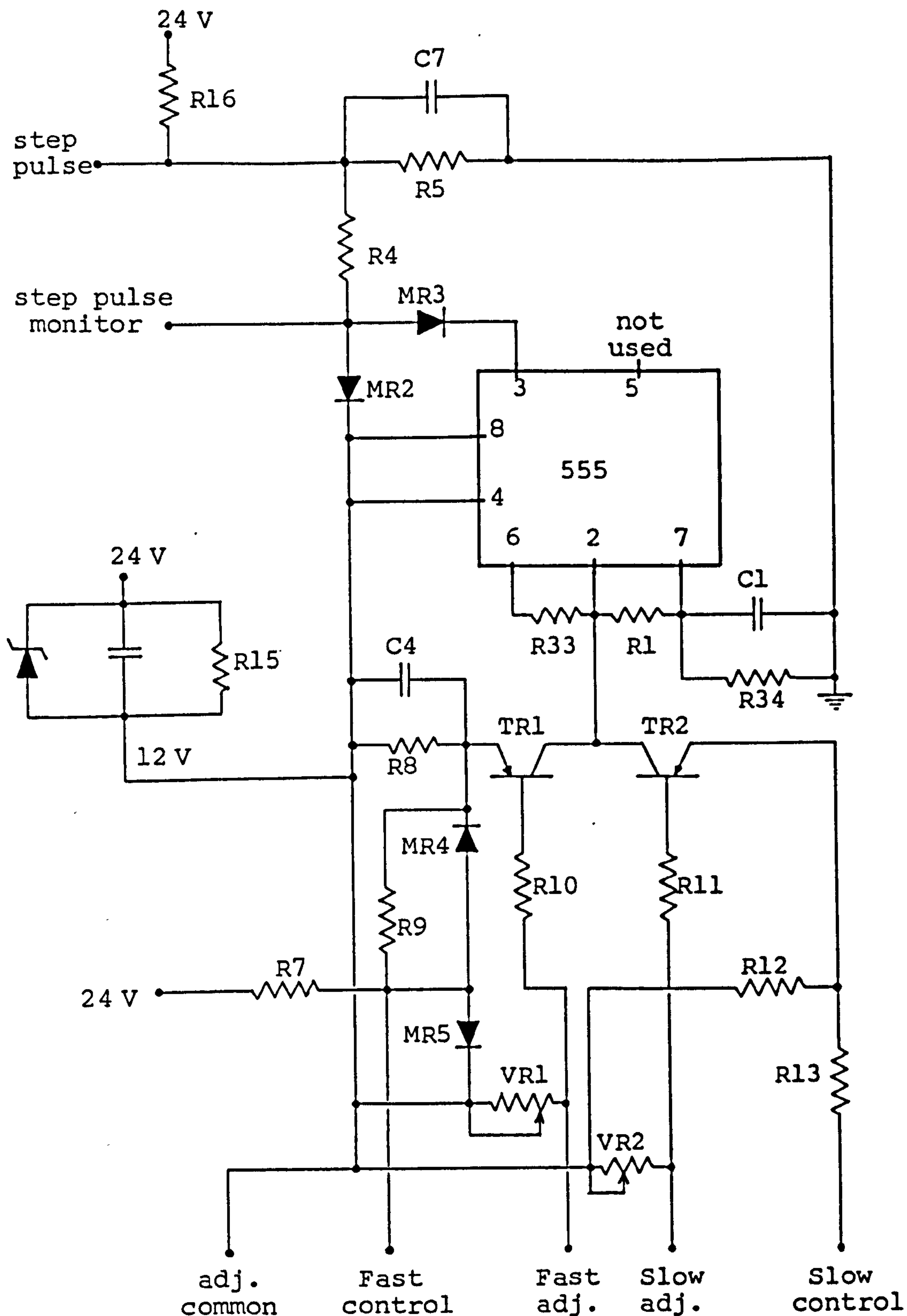
3.4.1.2 555 Oscillator with Ramping Control

To be ideally suitable for stepper motor drive the 555 requires further external controls. Ideally an oscillator should be able to run in the pull-in range of the motor instantaneously and then be ramped (gradually changed) for operation of the motor in the slewing region. Connections¹⁹² to achieve these functions are shown in Figure 3.29. The circuit is shown deriving its power from the same 24 V supply which can be used to drive the motor.

When the Slow control is brought to ground the oscillator runs at a speed controlled by C_1 , R_{11} and VR_2 which in this case will be set within the pull-in range of the motor. When the Fast control is brought to ground with Slow already on, the frequency will increase at a rate determined by C_4 and R_8 to a speed controlled by C_1 , R_{10} and VR_1 which in this case will be in the slewing range. An approximate formula for the frequency under these conditions is

$$f = \frac{4 \times 10^6}{R} \quad \text{steps/s}$$

$$\text{with } R = R_{11} + VR_2 \quad \text{for Slow}$$



R11 and VR2 control frequency when Slow control is earthed
 R10 and VR1 also control speed when Fast control earthed
 C4 controls ramping after Fast is earthed or opened
 Externals are added parallel to VR1 and VR2.

Figure 3.29 The 555 oscillator with ramping control.

and $R = R_{10} + VR_1$ for Fast.

Here R_{10} , in parallel with R_{11} , must be greater than 400 ohms and R must be less than or equal to 10 Mohms.

In the following discussion and later work the terminology adopted to describe electrical component values is as used by RS Components Ltd¹⁹³. Thus, for example, 400 ohms becomes 400R and 3300 ohms becomes 3k3.

With R_{10} of 470R and R_{11} of 3k3, and variable resistors VR_1 of 10k and VR_2 100k, a speed range of Slow 40-1200 steps/s and Fast 400-5000 steps/s is produced.

Alternatively the speed on the same circuit can be controlled by an analogue voltage. Both the Slow and Fast speed ranges can be controlled by connections in parallel with VR_1 and VR_2 respectively. These inputs can be considered as an 8k resistor between the input and 12 V. The relationships are linear, 0 V giving the pre-set speed and 10.5 V giving zero speed. The Fast and Slow speeds are additive. Changes in voltage on the Slow control are immediately translated into changes in speed. Changes on the Fast control are modified by the ramping capacitor C_4 in order to maintain acceleration profiles which will not desynchronise the motor. Care must be taken in any change upon the Slow control, as here there is no protection against loss of motor control.

This circuit offers many useful features in controlling stepper motor movement. The oscillator can be externally controlled through Slow and Fast controls with switches activated by a digital system or a microprocessor. Analogue control of the speeds is also possible with a built in ramping function.

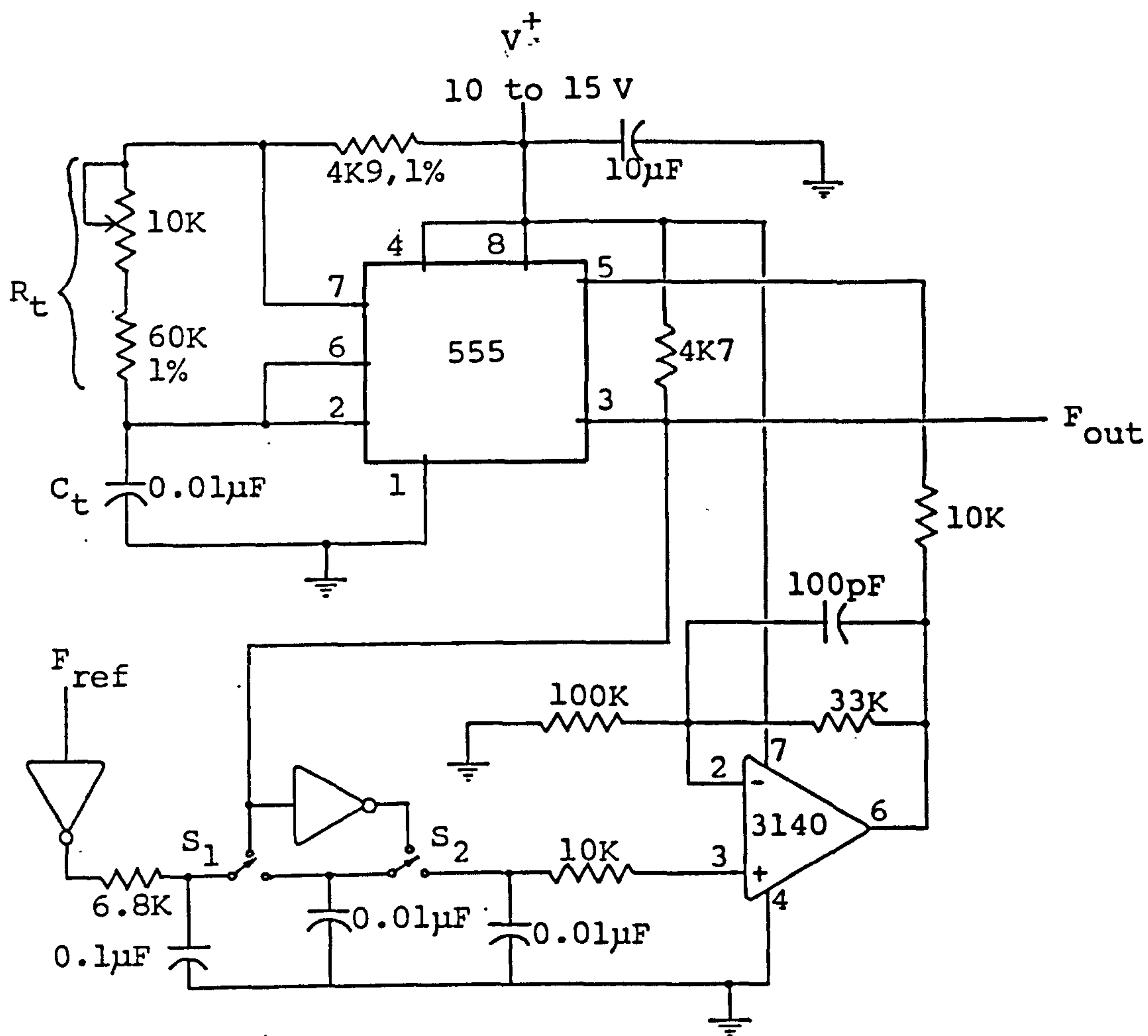


Figure 3.30 The 555 oscillator used as a phase locked loop.

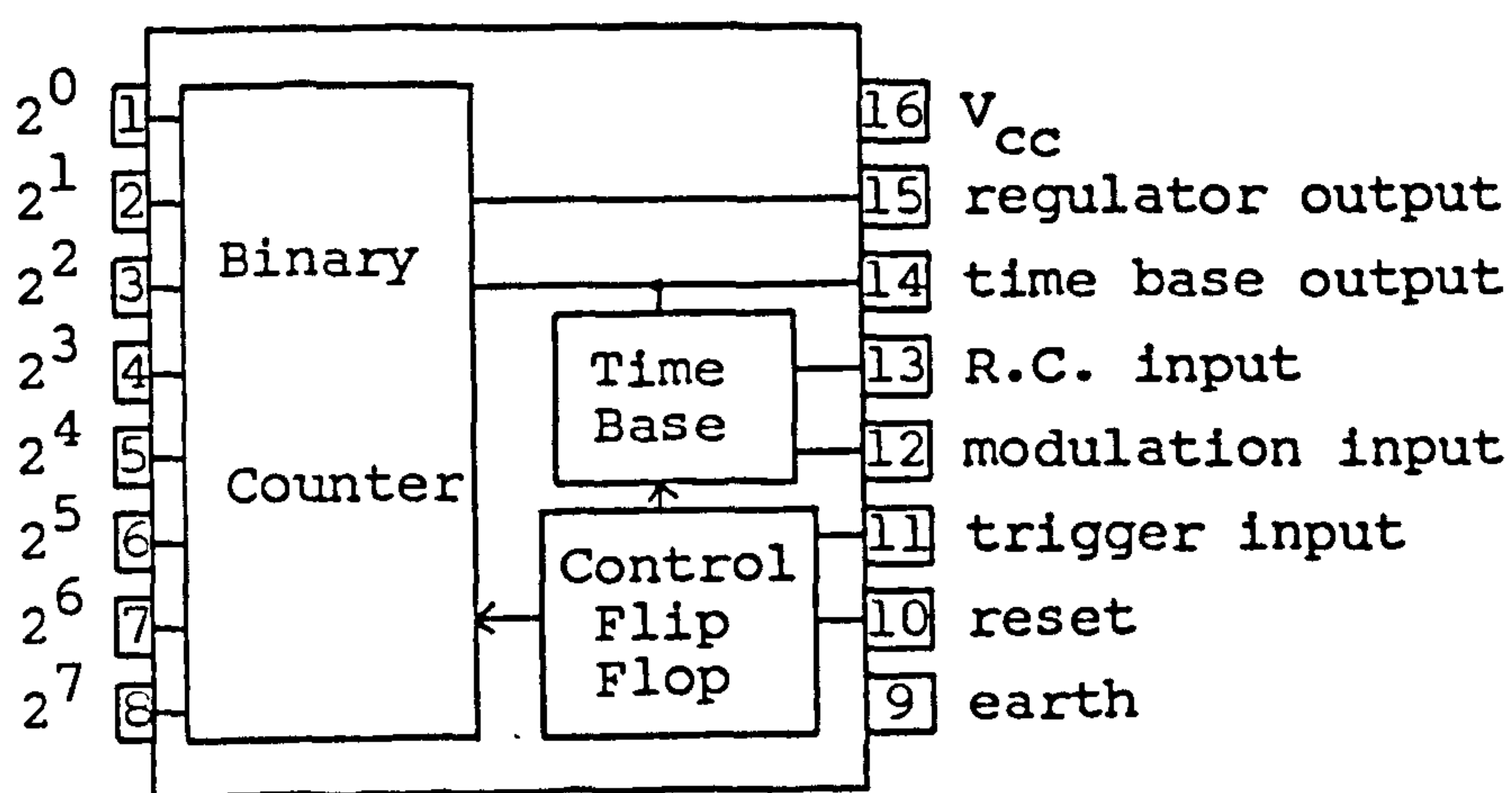


Figure 3.31 Schematic diagram of the 2240 timer.

3.4.1.3 555 Oscillator Used as a Phase Locked Loop

The 555 may also be used to generate frequencies that are related to an input frequency. If the machine movement is used to generate a high frequency pulse it may be necessary to convert this to a slower form still related to the original frequency. A frequency divider is then needed. To ensure that the frequency produced is always correctly related to the original frequency it is desirable to use a phase locked loop. Here the output frequency is referred back to the original frequency and corrected to ensure that the relationship is maintained. A phase locked loop circuit using the 555 is shown in Figure 3.30. A 3140 operational amplifier¹⁹⁴ is used to set the control voltage on the 555 dependent upon the action of a switching circuit using CMOS analogue switches and input buffers. The output frequency of the circuit equals the reference frequency divided by an integer, M . The choice of components (C_T , R_2 , R_3 and R_4) gives the M^{th} cycle of the reference frequency which, using the control loop, is compared with the output pulse. The output pulse is then adjusted to lock in sequence with this M^{th} cycle of the reference frequency.

3.4.2 2240 Programmable Timer

The 2240 programmable timing device belongs to a group of programmable timer-counters^{189,191}. The timer section consists of a 555 type oscillator and this is followed by an eight bit binary counter. This is shown schematically in Figure 3.31. The timer section generates a pulse of time period T . This is then multiplied or divided by the counter to effectively alter the timer period by a chosen factor.

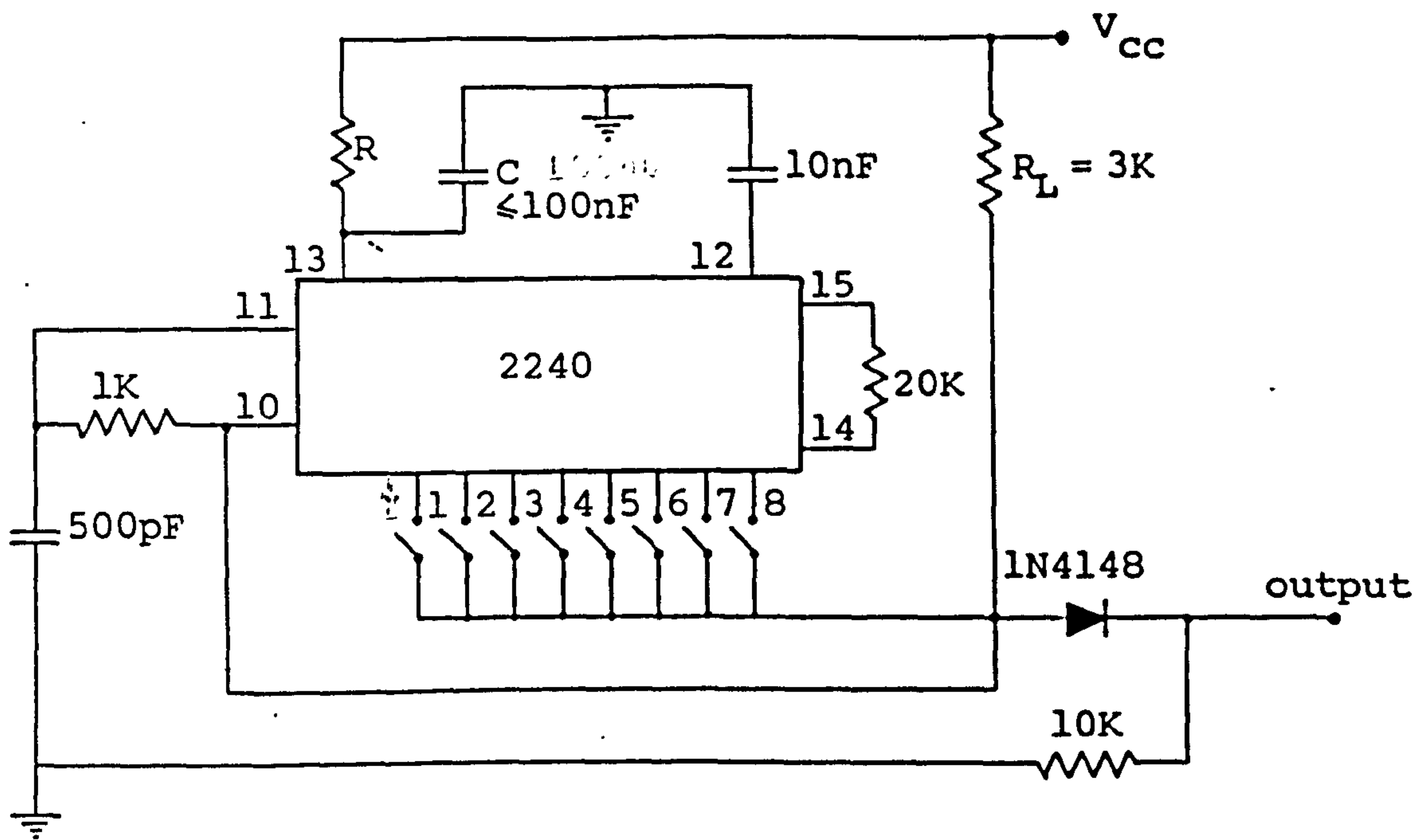


Figure 3.32 Connections for the 2240 as a frequency synthesizer.

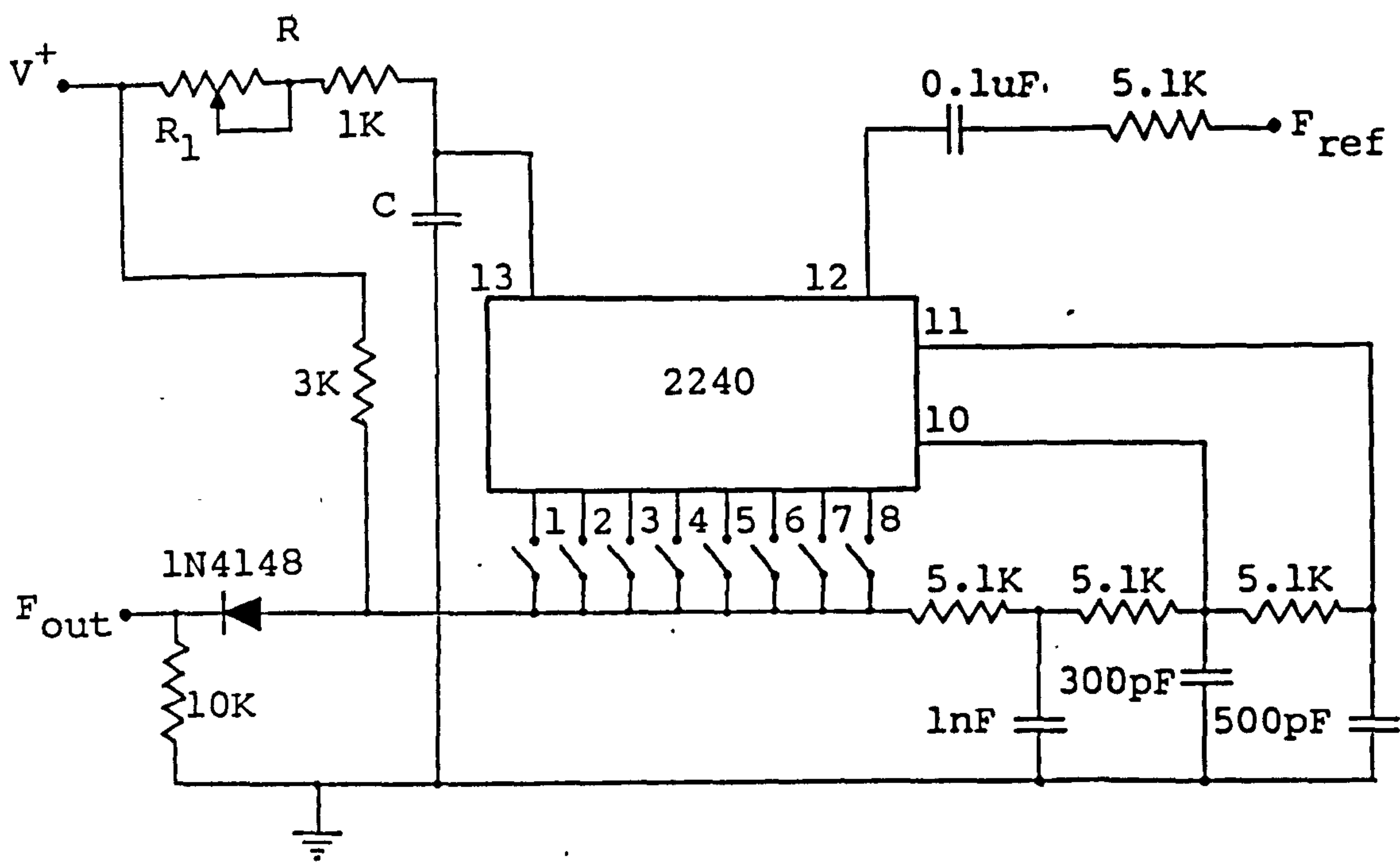


Figure 3.33 Connections for the 2240 as a frequency synthesizer with harmonic locking.

The factor can be made externally variable thus making the timer programmable.

To synthesize a range of frequencies for a given basic timing period, T , equal to RC , the connections are as given in Figure 3.32. As the binary counter outputs are open collector type, they can be shorted together to a common pull-up resistor to form a wired OR connection. The combined output will be LOW as long as any one of the binary inputs connected in this fashion is LOW. The time delays associated with each counter section will then be added together. Using this method, the timing period is $RC(N + 1)$ with a pulse length of RC . N is the number presented on the binary inputs. With only one RC combination 255 separate frequencies are selectable all of which are related to the base timing period. It is also possible by disabling the internal oscillator to apply an external clock pulse to the time base output and use this external pulse for frequency synthesis. This makes it possible to link motor controlling pulse trains with pulses produced by the knitting machine movement.

3.4.2.1 Harmonic Locking of the 2240

Frequency synthesis can also be achieved on the 2240 with harmonic locking. Here a given frequency can be achieved relative to an input frequency either above or below the original frequency. The time-base period, T , can be synchronised by setting it to be an integral multiple of the reference pulse period, T_{ref} . This is done by choosing the timing components R and C such that

$$T = RC = T_{ref}/M$$

where M is an integer such that $1 \leq M \leq 10$.

Connections for this circuit using the 2240 are shown in Figure 3.33. The output frequency is then related to the input reference frequency thus:

$$F_{out} = \frac{F_{ref} M}{N + 1}$$

where N is chosen by a wired OR condition on the counter sections. This circuit, with M less than 10 has a pull-in range for locking greater than 4% of the time-base frequency. The smaller M (the lower the harmonic chosen) the more stable the locking-in becomes.

3.4.2.2 2240 as a Phase Locked Loop

This circuit can be run as a phase locked loop to increase its stability. The necessary connections are shown in Figure 3.34. Here an error detection circuit, as used for the 555, feeds back the difference between the Mth harmonic of the input reference frequency and the output frequency and uses this to correct the output frequency..

3.4.3 Voltage to Frequency Conversion

The last of the standard devices to be considered for pulse generation is the RS 307-070 voltage to frequency convertor¹⁹⁵. This convertor combines both bipolar and CMOS technologies on a single circuit. A variable analogue voltage input signal is accepted and an output pulse train is generated which is linearly proportional to this voltage. A schematic diagram of this device is given in Figure 3.35. Instead of generating pulses from machine movement it is possible in this situation to generate a voltage using a device such as a tachogenerator¹⁹⁶ and control the frequency

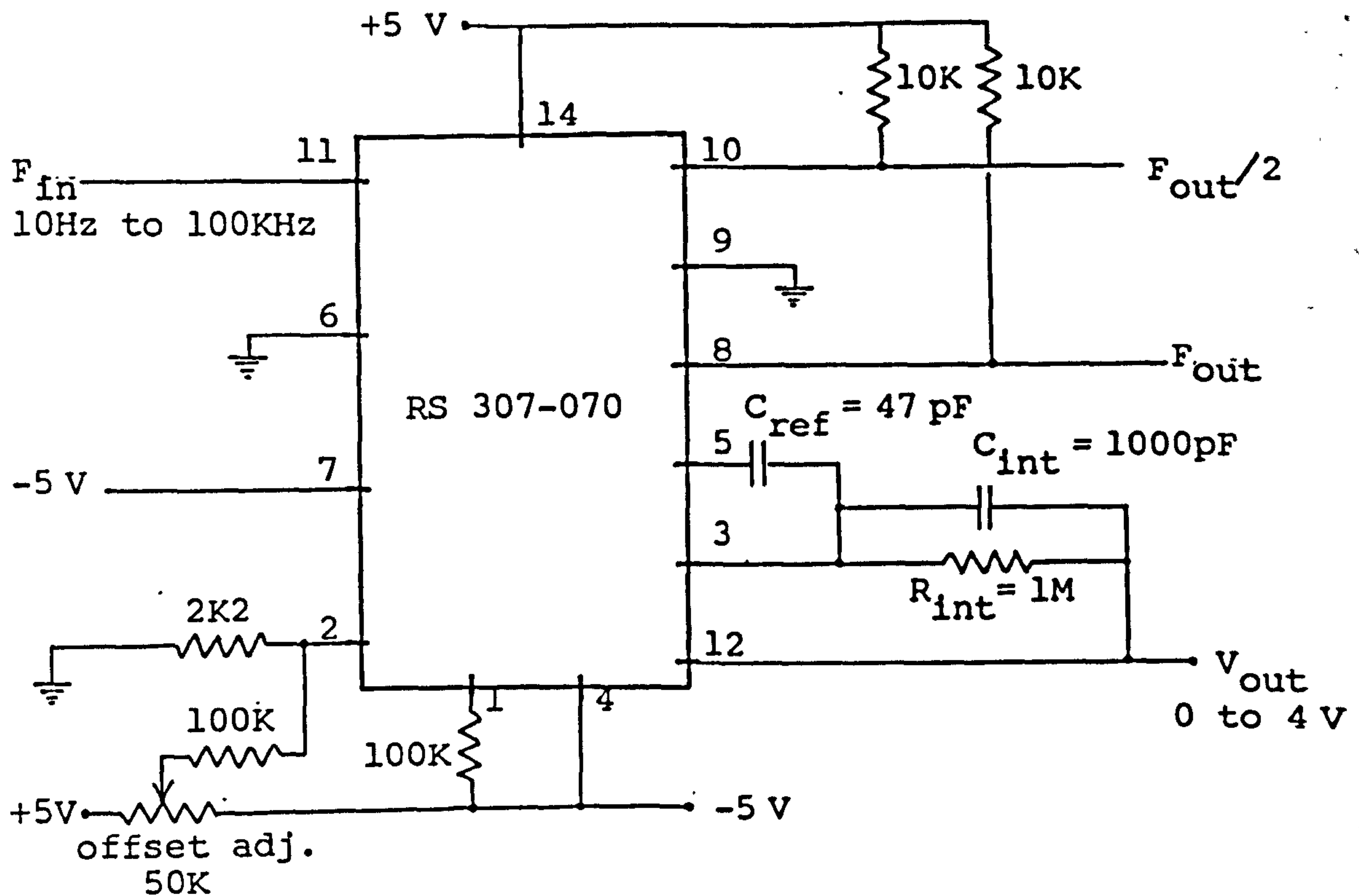


Figure 3.36 Frequency to Voltage connections for the RS 307-070 converter circuit.

$$F_{out} = V_{in} / R_{in} V_{ref} C_{ref}$$

$$R_{in} = V_{in,max} \times 10^{-1} M$$

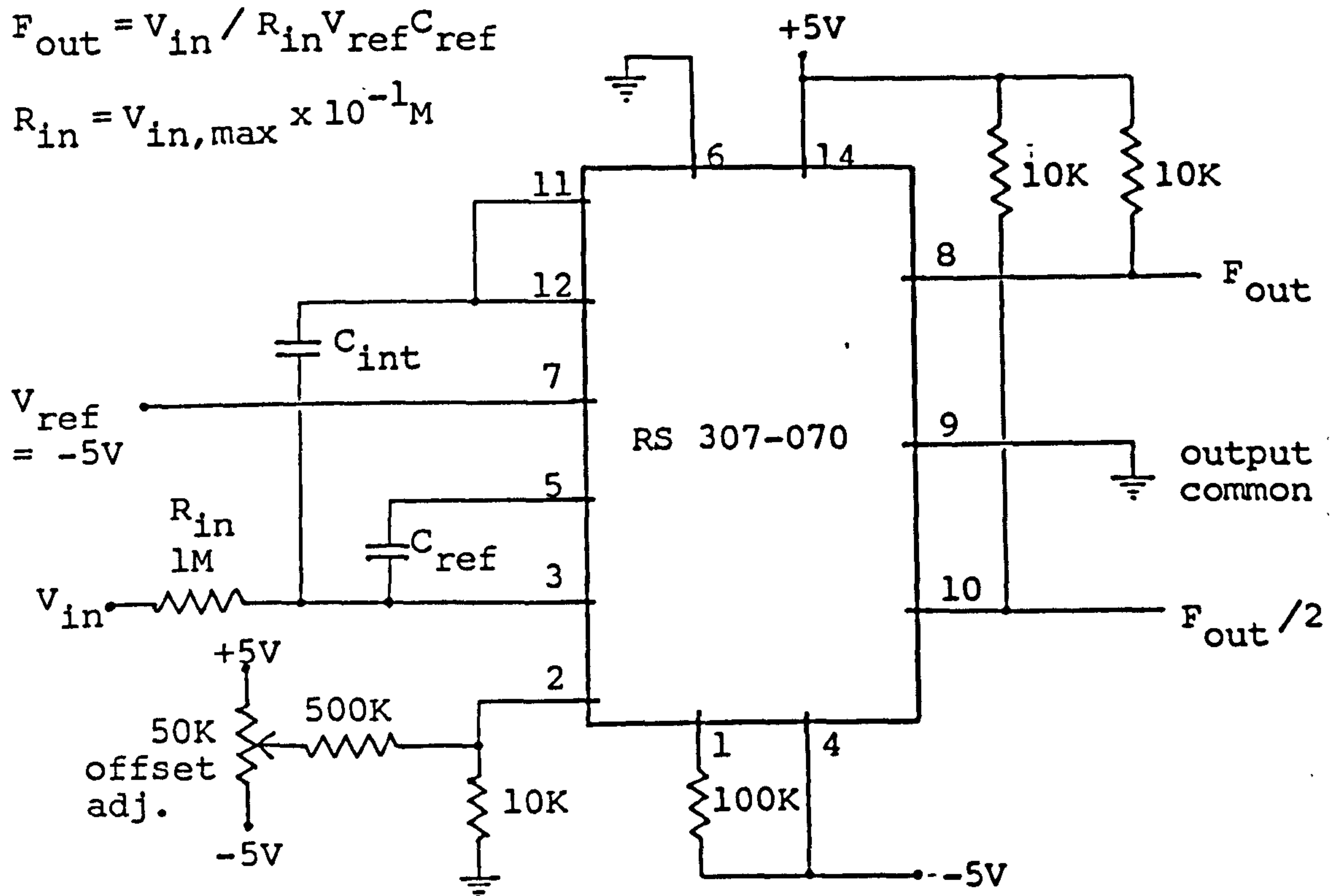


Figure 3.37 Voltage to Frequency connections for the RS 307-070 converter circuit

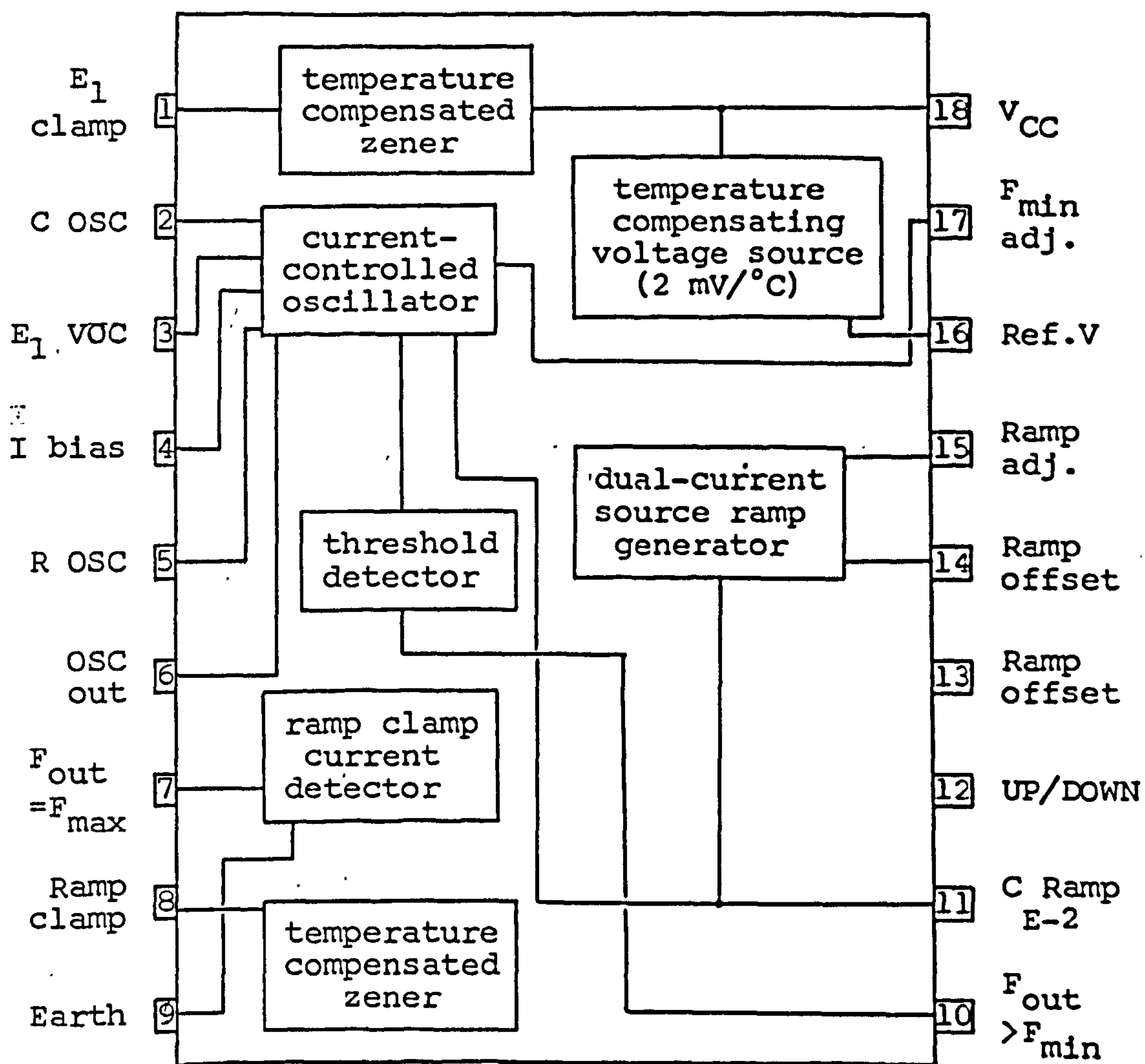


Figure 3.38 Schematic diagram of the Ramp Control Oscillator (RCO).

of motor pulses by this voltage. The connections for voltage to frequency conversion are given in Figure 3.36.

The RS 307-070 can also be used as a highly accurate frequency to voltage convertor, accepting virtually any input frequency and providing a linearly proportional voltage output. This mode of operation is more generally useful in metering operations for examining the performance of a system. The connections to give frequency to voltage conversions are shown in Figure 3.37.

3.4.4 Purpose Built Motor Control Circuits

As well as these standardly constructed devices for pulse generation and control, several circuits have been developed in an integrated circuit package specially for control of stepper motors. This type of device is much more expensive than a generally applicable device but does offer some particular application features.

The RCO (Ramp Control Oscillator) and RCL (Ramp Control Logic) are purpose built oscillator and oscillator control chips for use in stepper motor drives. These single package circuits, built using both bipolar and CMOS circuitry, utilise both linear and digital techniques and require no active components as externals to control the circuit functions.

3.4.4.1 Ramp Control Oscillator (RCO)

The RCO is shown schematically in Figure 3.38. This linear bipolar chip contains a precision voltage controlled oscillator for voltage to frequency conversions, as well as highly stable precision current sources for charging an

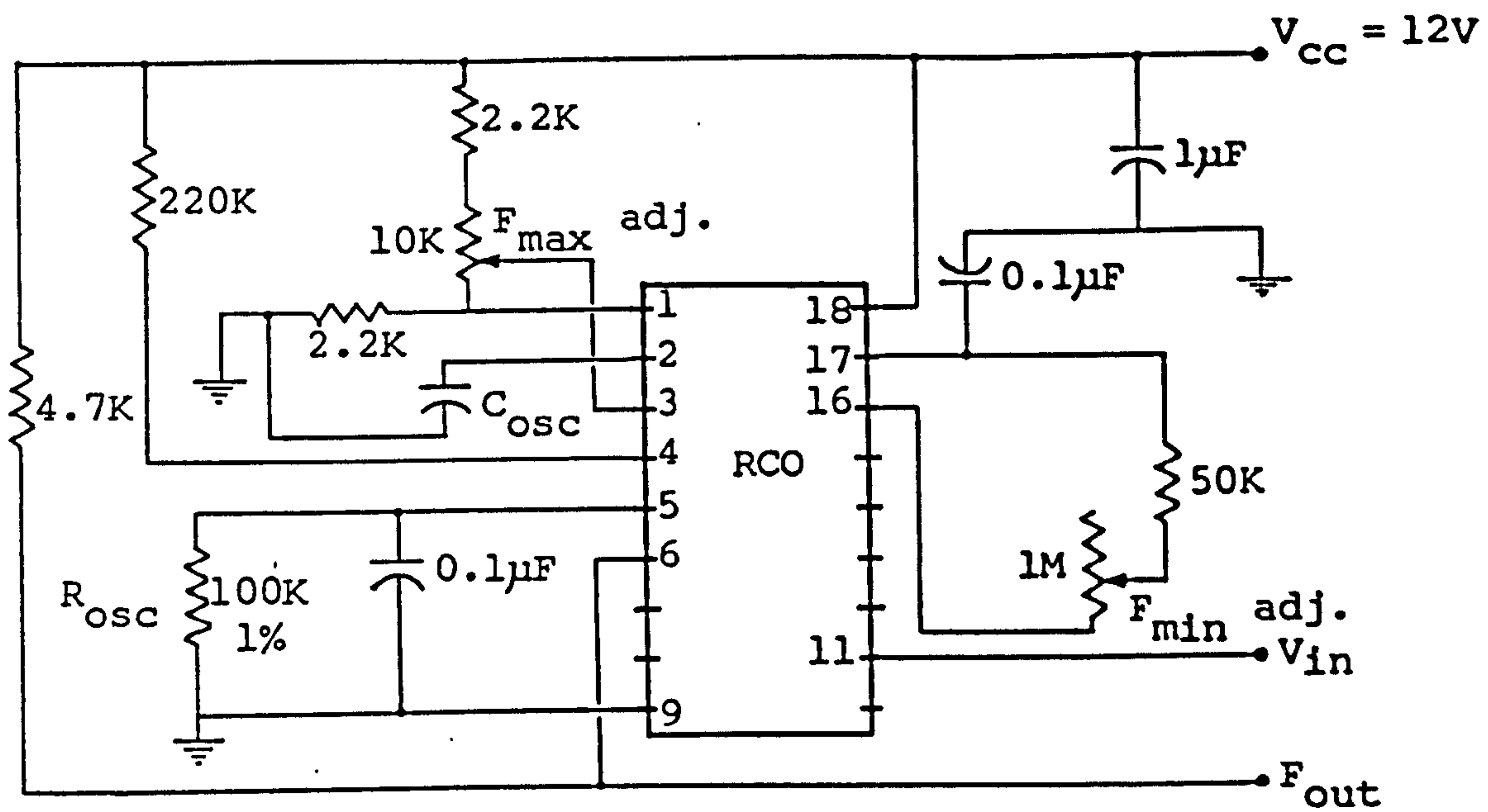


Figure 3.39 The RCO as a voltage controlled oscillator.

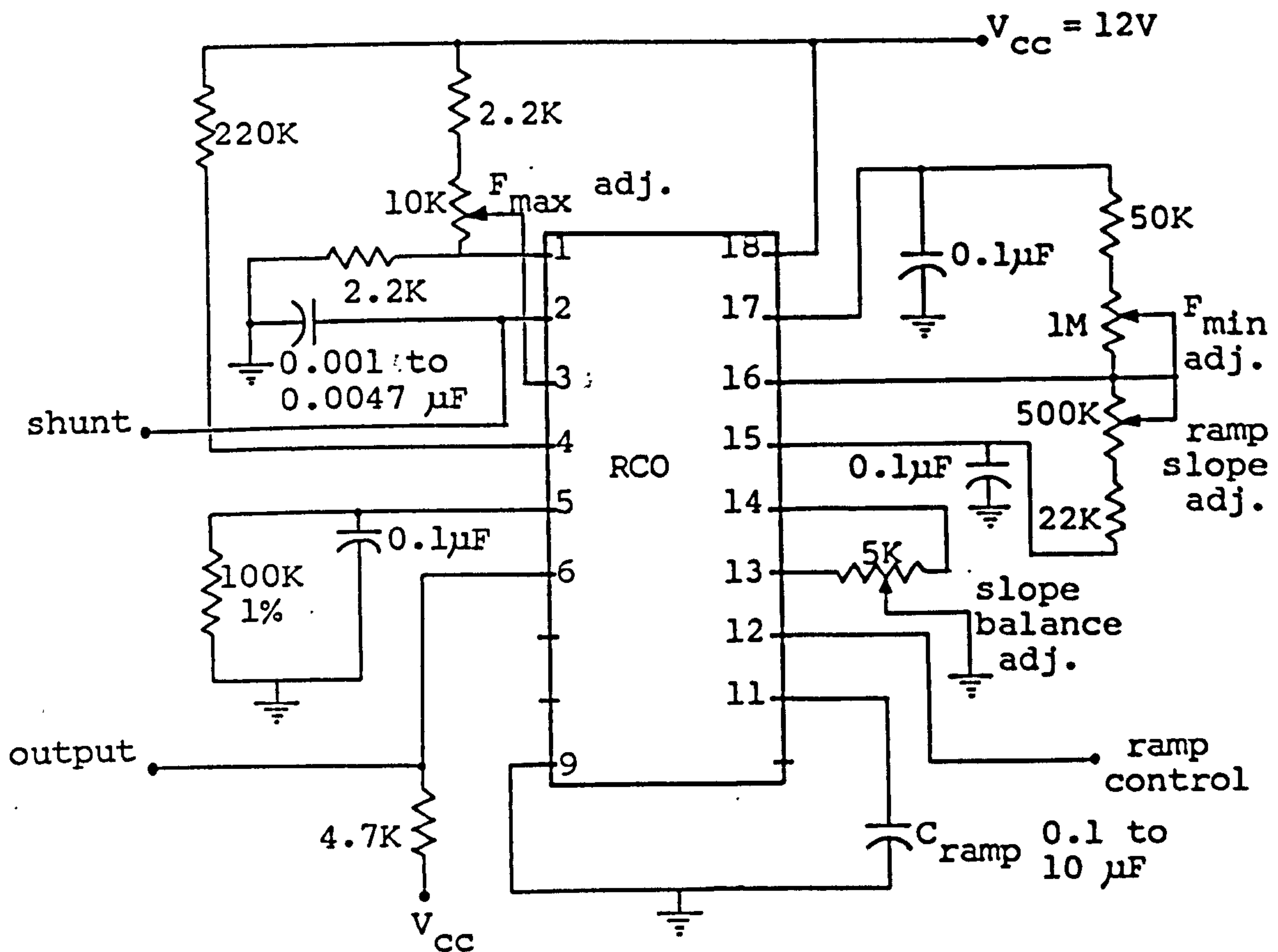


Figure 3.40 The RCO as a buffered ramp.

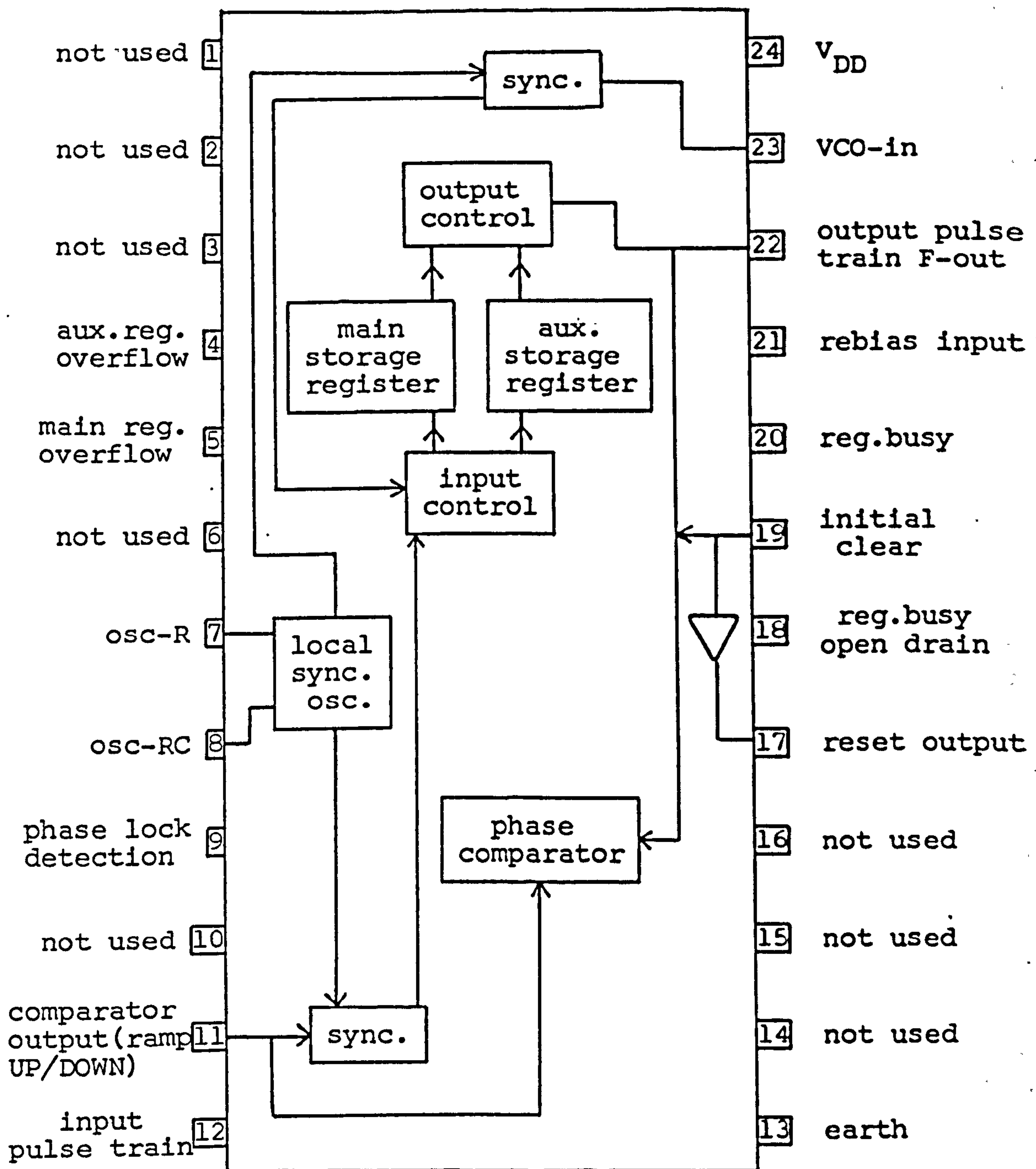


Figure 3.41 Schematic diagram of the Ramp Control Logic (RCL).

external capacitor to generate stable symmetrical voltage ramps. These voltage ramps are used to generate ramped frequency outputs from the voltage controlled oscillator section. This circuit can thus be used as a fixed or variable frequency source for simple speed control, a ramped frequency source for speed control external logic or as a parabolic response voltage to frequency convertor ($F=kV^2$) for wide range frequency control.

Connections to give a voltage controlled oscillator are shown in Figure 3.39. Here the frequency is controlled by a combination of the analogue voltage on pin 9 and the oscillator externals R_{osc} and C_{osc} . With the voltage on pin 9 from 0-12 V and C_{osc} between 0.005 μ F and 0.01 μ F a frequency range of 10 to 50,000 Hz can be achieved. If C_{osc} is kept constant at 0.005 μ F a range of 500 to 50,000 Hz is achieved changing V_{in} only.

Connections for ramp generation are shown in Figure 3.40. Here a linear ramp is generated with ramp times controlled by the ramp capacitor and the voltage between pins 15 and 16. With the components shown and a capacitor choice between .01 and 10 μ F ramp times from 0.001 to 10 seconds can be obtained.

3.4.4.2. Ramp Control Logic (RCL)

A schematic representation of the RCL is shown in Figure 3.41. This circuit is primarily used to provide a phase locked loop buffered ramper with the RCO. This means that a variable frequency pulse train with controlled acceleration and deceleration characteristics can be achieved from a fixed frequency burst of pulses. Pulses "put aside"

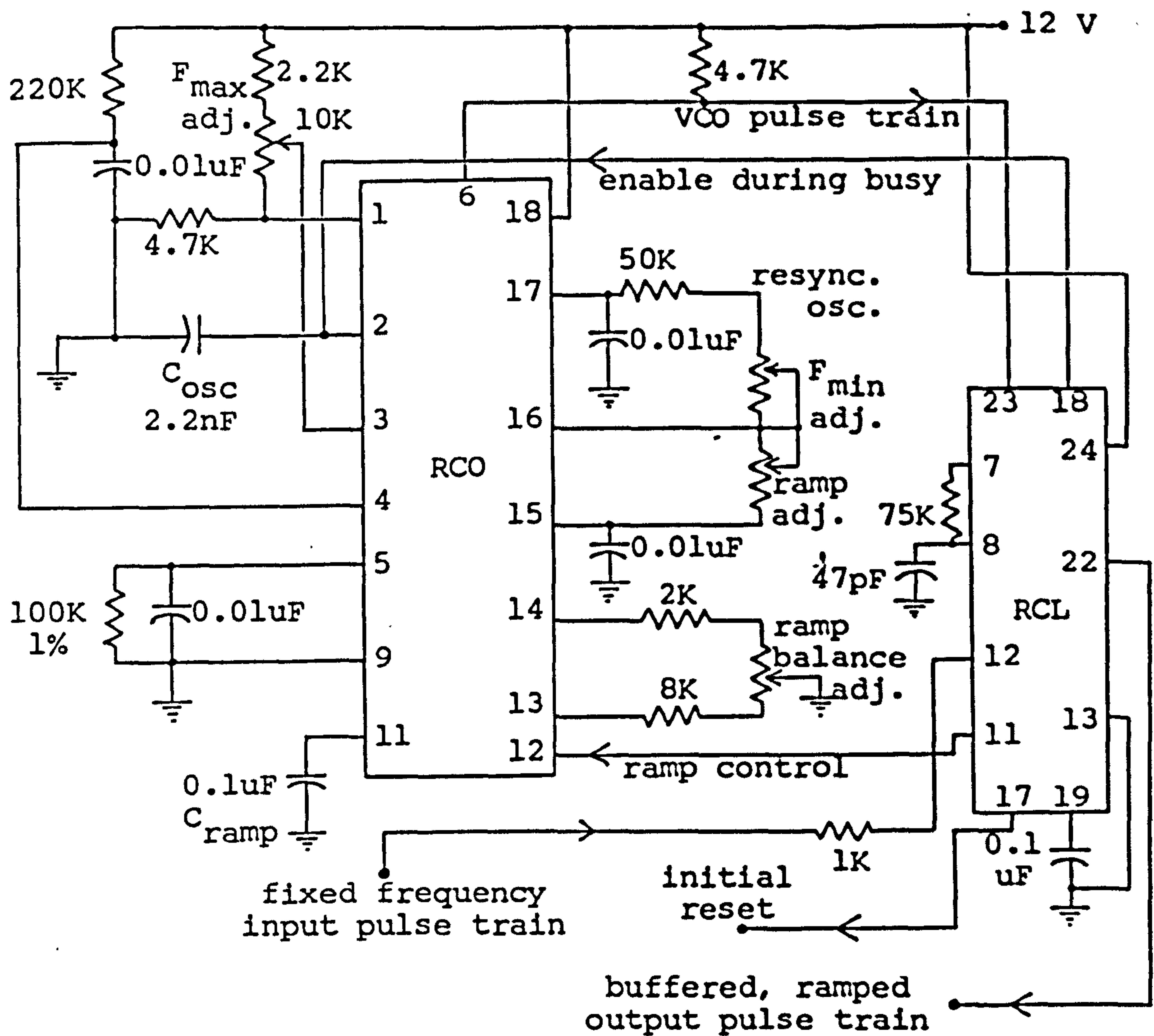


Figure 3.42 RCO and RCL combined as a buffered ramper.

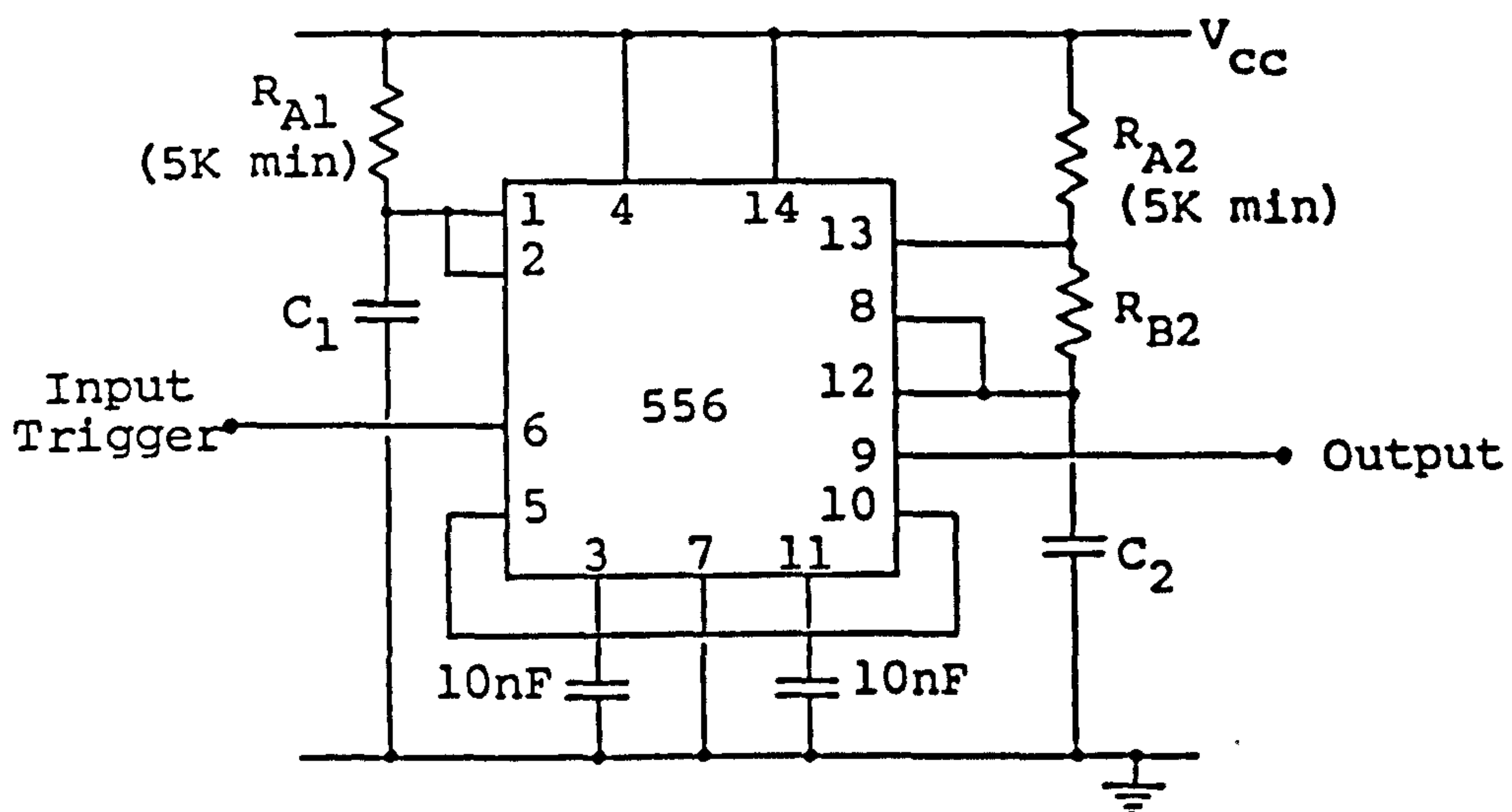


Figure 3.43 The 556 used as a tone burst generator.

during acceleration are "put back" during deceleration. This enables smooth motor response to be maintained while the number of pulses is preserved. The connections to give this are shown in Figure 3.42.

For yarn feed this means of control will prove extremely valuable. It is possible to switch in a burst of pulses and have them correctly ramped and presented to the motor. The means of producing the burst of pulses must still be examined. The 555 circuit again can be used. By combining two 555 circuits, one in the monostable mode and the other in its astable mode, the required result can be achieved. The monostable pulse is used to turn on the second astably connected circuit and then turn it off after the required time. A 556¹⁹⁰ circuit is available which combines two 555s in one package and is hence ideal for this application. Connections on this package as a "tone burst" generator are shown in Figure 3.43. Here R_{A1} and C_1 control the length of the monostable pulse while R_{A2} , R_{B1} and C_2 control the frequency and pulse width of the burst of pulses.

3.4.5 Microprocessor Pulse Generation

As an alternative to the systems requiring special circuits and external components, a microprocessor can be used to generate the stepping pulses. As discussed previously, to use a Commodore PET or similar microprocessor to gain the full performance of a stepper motor, the programming must be undertaken in machine code. In Basic, speed is severely limited due to the interrupt routines and the motor would operate only in its pull-in region.

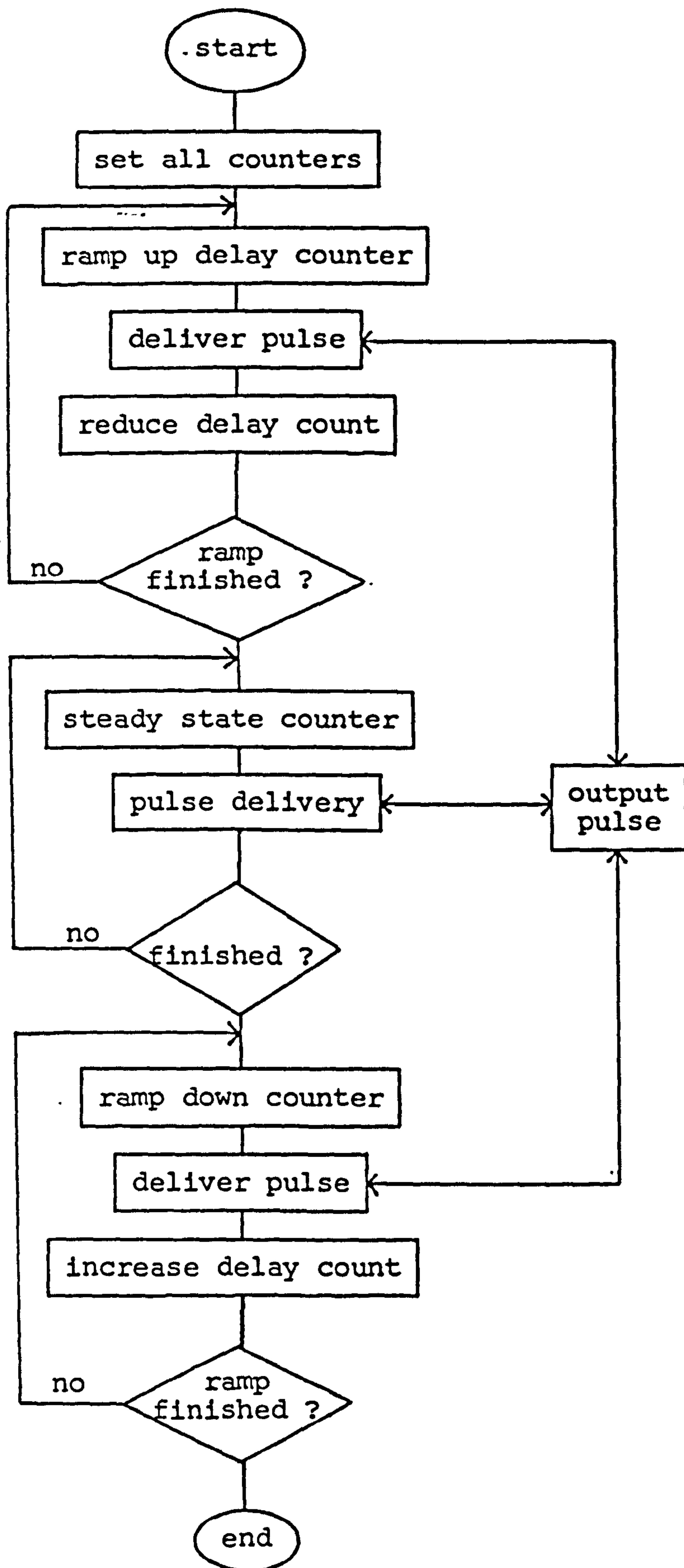


Figure 3.44 Flow chart for the software controlled ramped generator and oscillator.

3.4.5.1 Direct Loading of the Input/Output Port

A pulse train can be placed on the output port by alternatively placing 1 and 0 on one of the lines. Here the translation to drive the stepper coils will be controlled externally.

When running with the very high internal clock frequency (1M Hz) used for machine code control, ramping controls must be used. If the frequency at which the motor will start is known then this can be used as the base frequency. If this is 1000 steps/s with the cycle rate of 1M Hz (1,000,000 cycles/s) 1000 cycles must be counted between each pulse delivered. To accelerate the motor this delay between pulses can be gradually reduced until the required frequency is reached (5000 cycles/s requires a count of 200 between each pulse). The rate of delay reduction determines the ramping of the motor in the slewing region of operation. To decelerate the motor this process is reversed, gradually increasing the delay time between pulses delivered until the pull-in region is reached. From here the motor can be stopped in a known position.

This system is a software controlled ramp generator and oscillator. A flow chart is given in Figure 3.44.

With this system it is possible to control eight motors simultaneously on the eight output lines or to deliver all the pulses down one line and use the other lines to select the motor to which the pulses are delivered. As the clocking speed of internal control is much faster than the pulse rate to be delivered to the motors, it should be possible to control a number of motors in this manner.

3.4.5.2 Parallel In, Serial Out Facilities on the Output Port

Alternatively to the method described above the pulses can be delivered using a special feature of the 6522 output controller used in the Commodore PET microprocessors^{156,197}. The 6522 has an internal parallel in, serial out shift register. Data is loaded into this register in a similar manner to loading into any of the 8 bit internal registers. The data is then shifted out onto the CB2 line under control of either Timer 2 and the system clock, or an external clock. This serial output can be controlled in four different modes. The free running mode is the most useful for controlling the frequency of pulse delivery. In this mode the shift register acts cyclically with output from bit 7 fed back to bit 0. The rate of data delivery is controlled from Timer 2. This Timer is a pre-settable counter, counting the number of clock pulses. On each pulse the counter is decremented. If the content is zero a pulse is output on the shift register thereby shifting the contents one bit to the right. At the same time the Timer is re-set to its original value and the process repeated. In this way a repeated pattern of 8 bits can be shifted out on the CB2 line at a particular frequency totally independent of processor control. This pulse delivery is fully synchronised with any microprocessor functions taking place simultaneously. This method gives a free running pulse rate from 490 to 500k Hz. To utilise this as a frequency pulse for motor control the time for delivery of the pulses at a given frequency (and hence the number of pulses delivered) must be controlled. A machine code program is used to read frequency and duration from a table and then control the shift register to present this on the output line. A flow

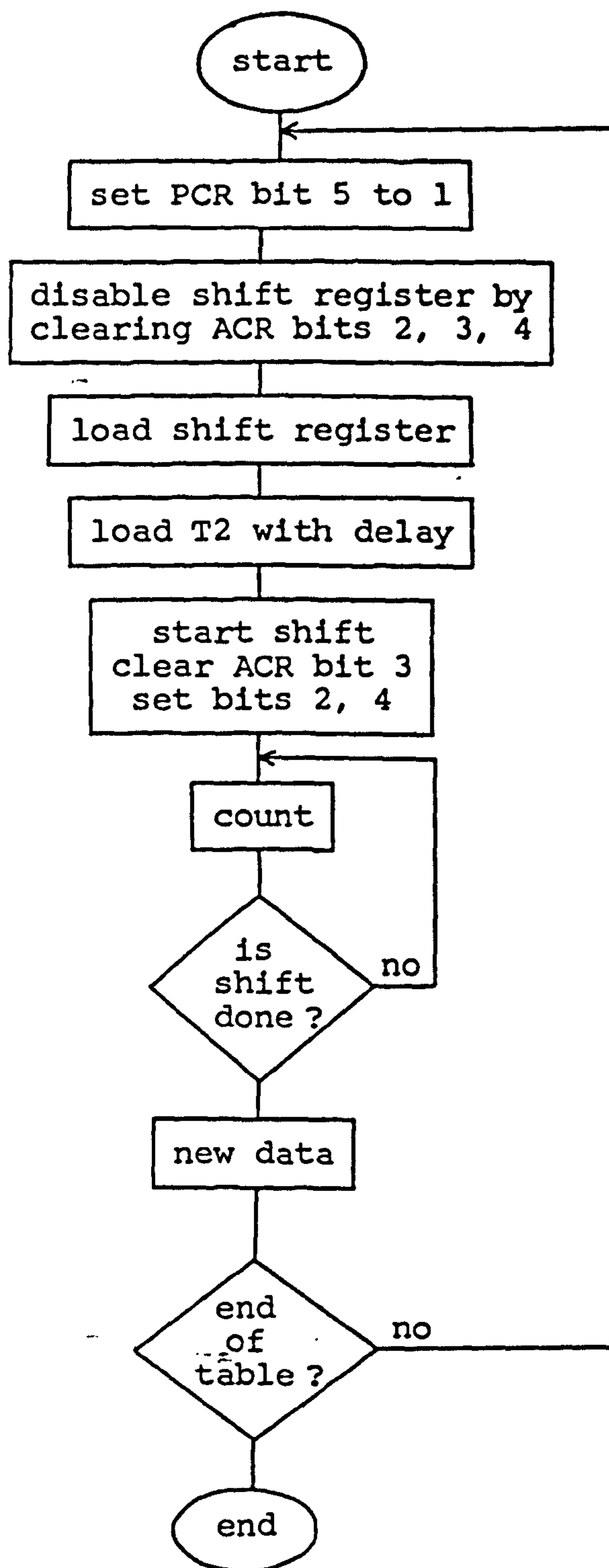


Figure 3.45 Flow chart for control of pulse frequency and duration on parallel in, serial out register.

chart for this function is given in Figure 3.45 and a machine code listing is given in Appendix 15.

This method uses only one output line leaving the eight user selectable Input/Output lines free for switching functions to control several motors.

The choice of pulse delivery method will depend upon the required flexibility of the system and must be matched to the application needs. When a microprocessor is used for other machine control functions it may be the most suitable, while where low cost is important those based on the 555 provide the cheapest alternative but require additional external control components to any system using the RCO and RCL circuits. Where linking to machine speed is necessary a phase locked loop circuit may prove the most useful provided it can be linked in with the accelerating and decelerating machine.

3.5 Commercial Drive-Boards

While a microprocessor is capable of providing the oscillator and translation to operate the stepper motors at high speeds, the current required in the coils requires higher current carrying capacity than is available on the microprocessor. Hence it would always be necessary to supply external current switching. Also to provide direct translation four output lines would be required per motor. When a system requires a large number of motors (e.g. on a circular knitting machine) any microprocessor implementation would seem to be severely restricted. However on a flat bed machine usually only two motors would be driven at one time. Here it would seem

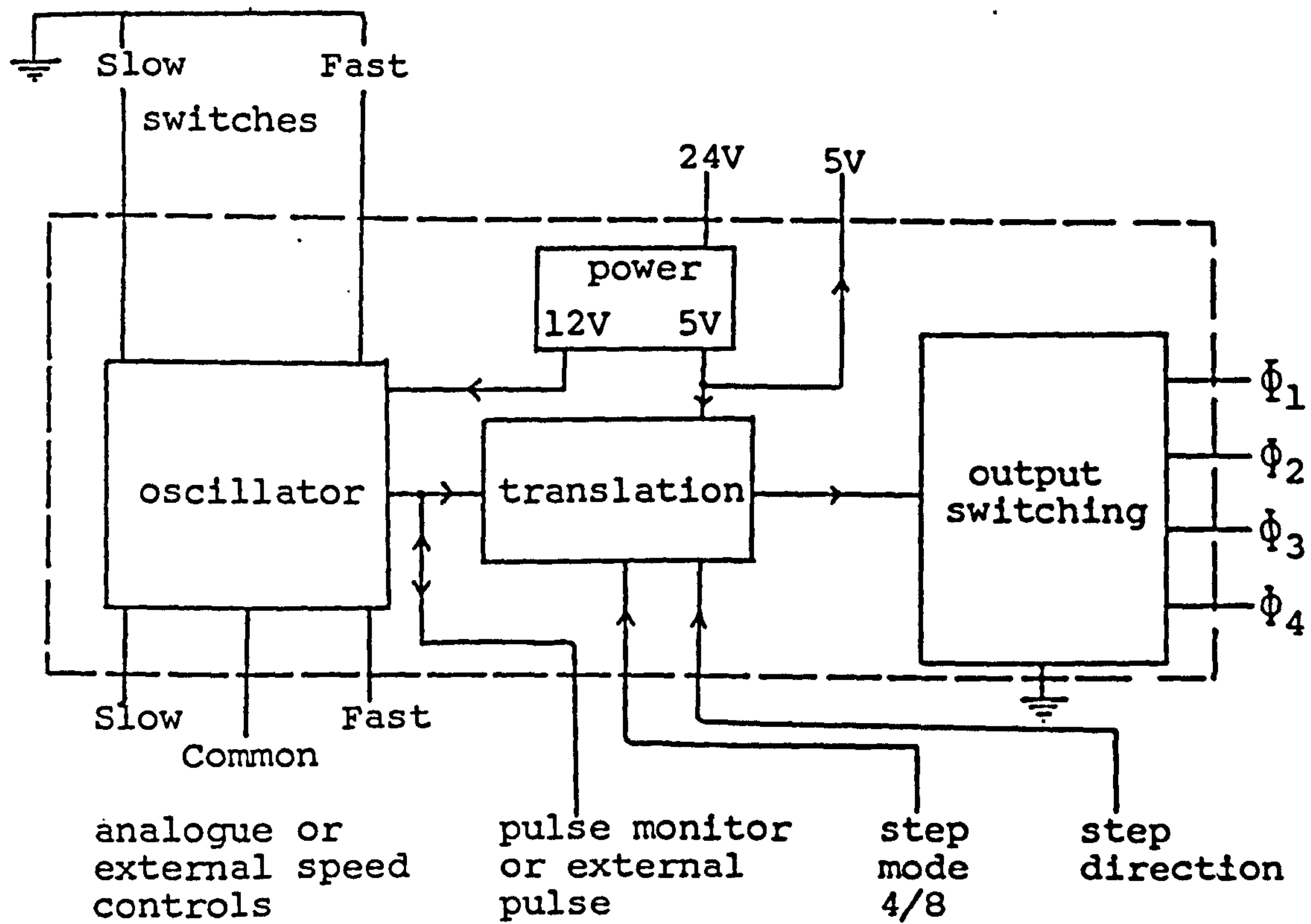


Figure 3.46 Schematic representation of the 053/1 drive board.

that a microprocessor could be used for control functions. The Commodore PET offers eight Input/Output lines and two edge sensitive inputs. If the oscillation, translation and coil switching are provided externally then the microprocessor can be used in a closed loop arrangement with the oscillator and hence control the simultaneous movement of two motors.

Two suitable control boards are available commercially which provide oscillation, translation and coil switching. These are the UDB 053/1 unipolar¹⁹² and the Digiplan LD2 bipolar drive¹⁹⁸.

3.5.1 Unipolar R/L 053/1

The UDB 053/1 board is a unipolar resistance limiting drive capable of two or four phase switching up to 5 A/phase. The coil switching is provided using 2N2033 transistors. The translation is by means of standard TTL logic based on three JK flip-flops with other logic to provide either four or eight step sequences in either direction. This will give 200 or 400 steps per revolution from a nominal 200 step per revolution motor. The internal oscillator is based on the 555 circuit. The oscillator arrangement provides separate Slow and Fast controls enabling the Slow range to be set in the pull-in range while the Fast control has ramping facilities and so can be used to slew the motor. This oscillator circuit was previously discussed in section 3.4.1.2. With this board the pulse may be either derived from the internal oscillator or from an external source. Analogue control facilities are also provided for both Fast and Slow speed controls. The drive board is shown schematically in Figure 3.46.

As this board can switch up to 5 A/phase it can be

053/1

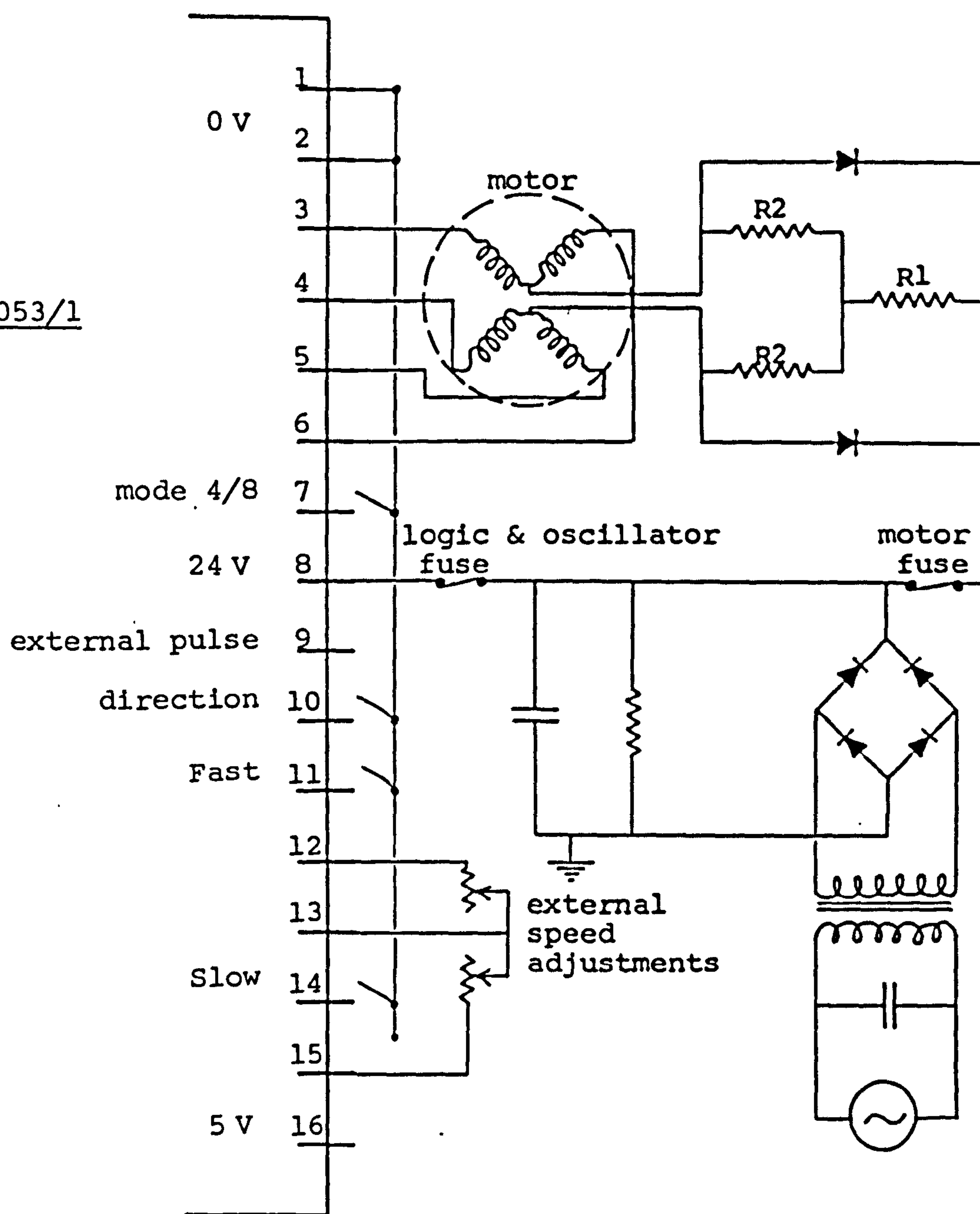


Figure 3.47 External connections for the 053/1 drive board

used to drive both the 20-2215D200-E1.5 motor at 1.5 A/phase and the 17-2220D200-E033 motor at 3.7 A/phase. External connections onto the drive board are shown in Figure 3.47. Here an unregulated 24 V power supply is used for all power required. The current capabilities of the supply should be chosen to match with the currents used in the motor switching. External resistors are chosen for a given motor current according to the following relationships.

$$R_1 = R/2 \quad R_2 = R$$

where
$$R = \frac{24 - V_m}{I_{ph}}$$

and
$$V_m = \text{rated motor coil voltage}$$

$$I_{ph} = \text{rated current per phase with two phases energised.}$$

The wattages of R_1 and R_2 are chosen such that

$$R_1 + R_2 = (24 - V_m) I_{ph} \text{ watts.}$$

is a minimum value.

To limit extremely high surface temperatures, resistors should be chosen which have ratings of approximately twice this value.

For the 20-2215D200-E1.5 motor, which has a phase resistance of 1.5 ohms and a rated phase current of 1.5 A, R_1 is chosen at 3.5 ohms and R_2 at 7.0 ohms each of 35 watts. The 17-2220D200-E033, utilising a higher current with a lower phase resistance, requires R_1 of 1 ohm and R_2 of 2 ohms allowing for 120 watts to dissipate as heat. Under these conditions the motors can achieve the 24 V unipolar ratings as discussed in section 3.2.7.

This board is however quite expensive (approximately £50) due to the high current transistors and the heat

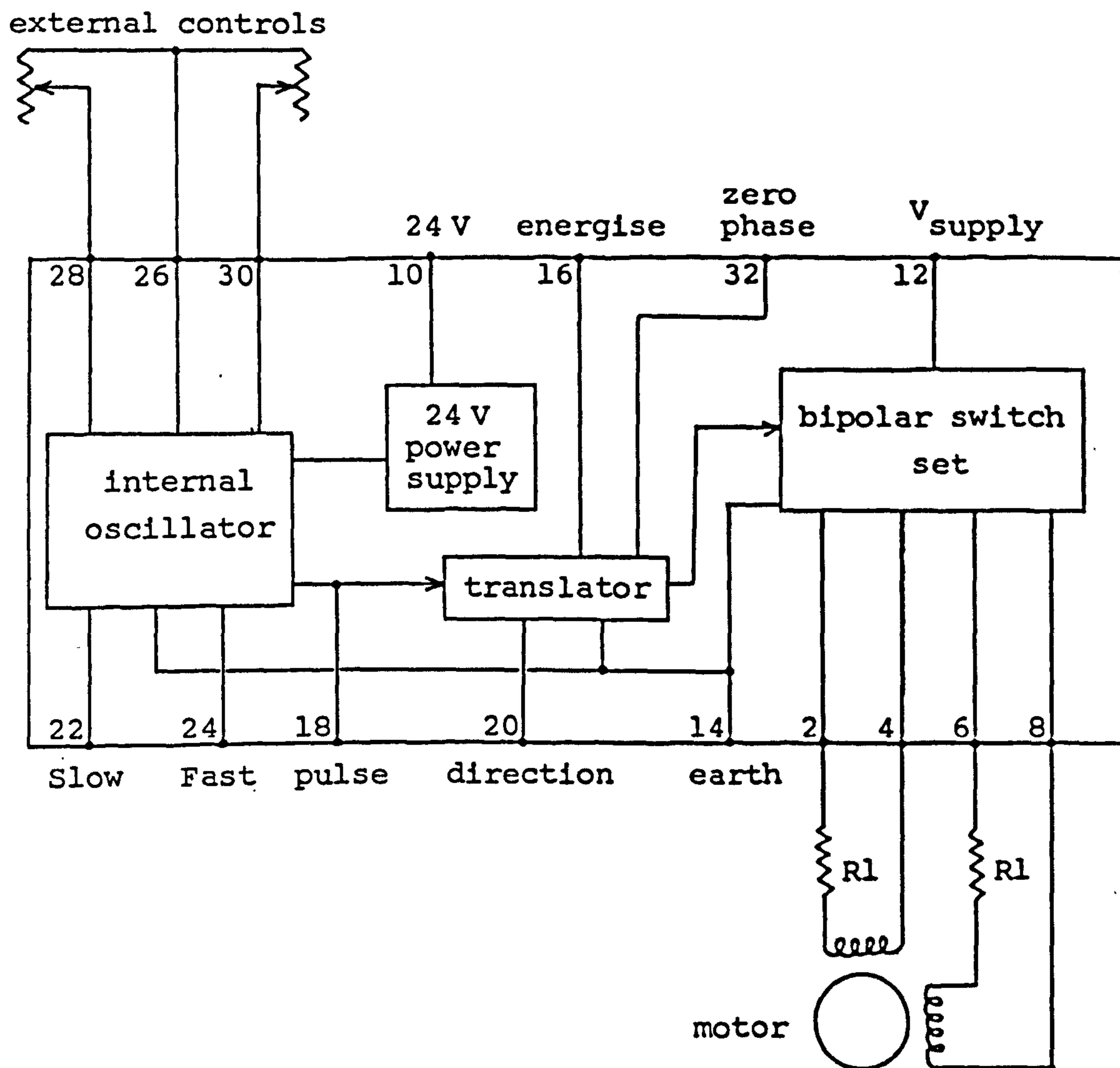


Figure 3.48 Schematic diagram of the LD2 drive board.

dissipation facilities needed. While for the 3.7 A switching this cost cannot be reduced, for the 1.5 A switching lower rated transistors with smaller heat sinks could be used. As the TTL logic and 555 oscillator are very cheap components, this could give a saving of approximately 15%.

3.5.2 Bipolar R/L LD2

Using lower current will obviously cut the cost of components used on the drive board as well as requiring less power to drive the motor. To maintain the motor performance in a range usable for this work however a bipolar switching circuit must be used with its resulting increase in components. As long as the current is such that heat sinking and expensive transistors are not required this will still give a saving in cost. The current is generally limited to under 1 A.

The LD2 board is produced as a low cost bipolar drive system. It has switching capabilities up to 0.8 A/phase with a bipolar output for high motor efficiency. This board uses CMOS logic based on an UP/DOWN counter to provide the translation into either four or eight step sequences in each direction. A 555 based oscillator is included in the system with related Slow and Fast range control. The switching is provided by an "H" drive using BC 640 and BC 639 transistors¹⁷⁷. The drive board is shown with external connections in Figure 3.48. This drive is equipped with a de-energise facility which allows the current to be switched out of the coils when the motor is not needed or where it is required to be turned to a start position. A datum position is also given which is one of the eight step positions. To

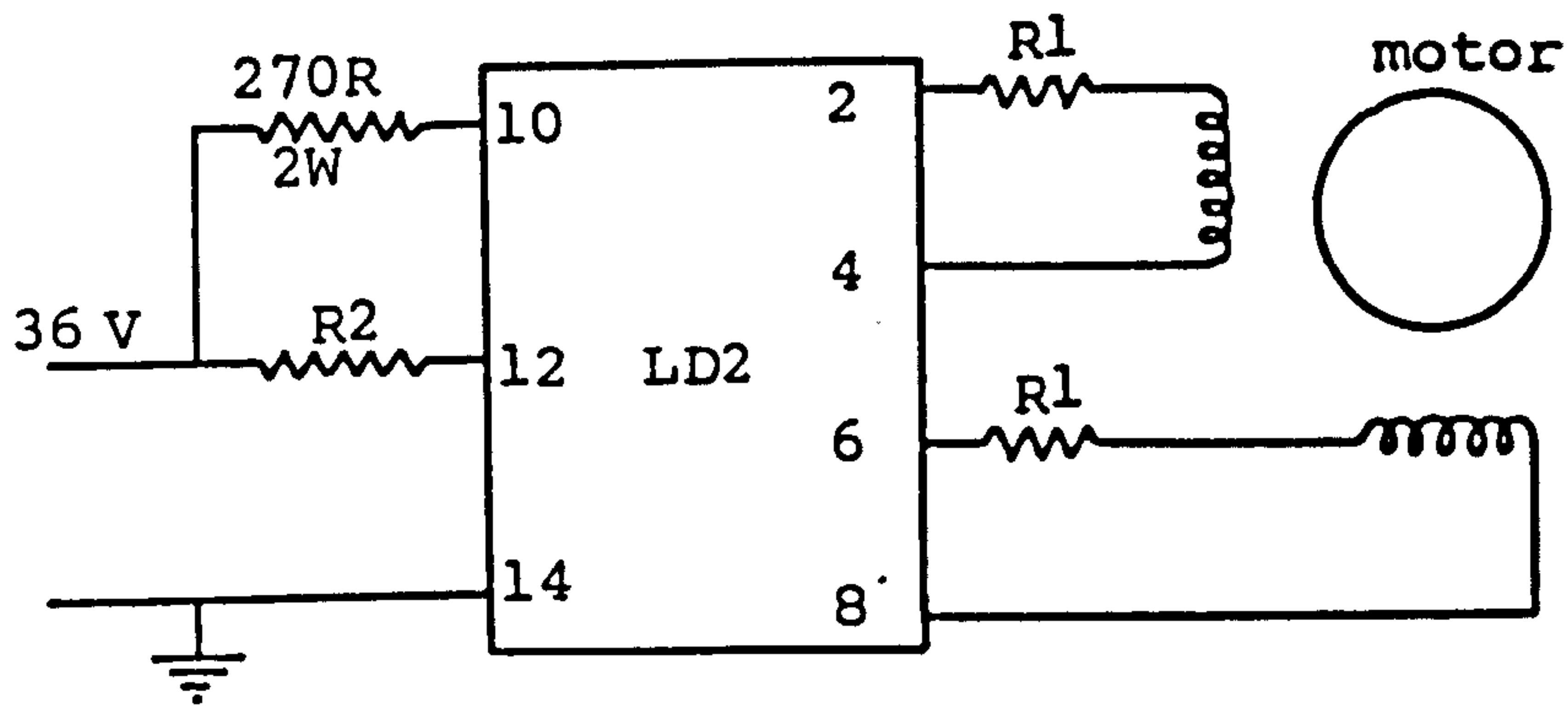
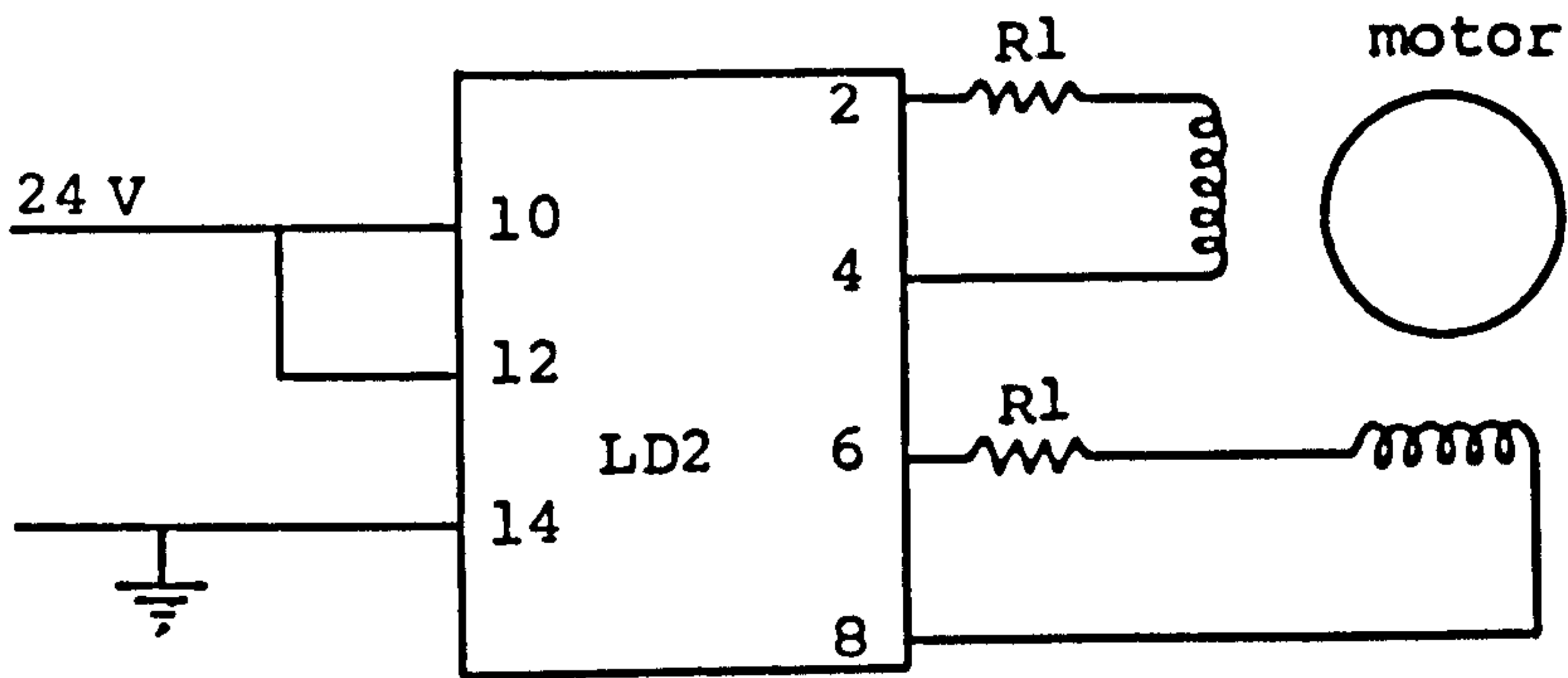


Figure 3.49 Drive connections for the LD2 board at 24 V and 36 V.

protect the transistors from shorting out one arm of the "H" the motor is usually driven in its eight step sequence.

Facilities are given to drive the motor from either 24 V or 36 V unregulated supplies. Connections for this are shown in Figure 3.49. R1 is chosen to give

$$R1 = \frac{22 - V_m}{I_m} \quad \text{ohms}$$

where V_m = motor volts per phase rating

and I_m = rated motor current (A).

The power dissipation required here is $R1 I_m^2$ watts and again it is better to have resistors of power rating twice this to avoid high temperatures.

If 36 V are used the voltage must be dropped through a 270 ohm resistor for the logic and oscillator supply while a third resistor is introduced into the motor drive stage. Here R2 is chosen such that

$$R2 = \frac{R1 + R_m}{2}$$

where R_m is the motor resistance per phase.

The power dissipation in R2 is approximately $330/R2$ watts.

For the 20-2220D200-E5.1 motor the resistors used are R1 of 15 ohms with 10 watt rating and R2 (where used) of 10 ohms with 50 watt rating.

The price of this drive unit is about half that of the 053/1, basically because heat sinking is not required and, although the "H" drive bipolar switching arrangement is used, the low current transistors are cheap. Biasing resistors capable of dissipating 2 watts are required on the drive board.

3.6 Microprocessor Systems for Motor Control

To control pulse delivery using the drive boards previously discussed switching of the oscillator must be introduced. This can be done by means of a microprocessor^{173, 174, 199}. With either of the systems using the 555 ramp controlled oscillator the microprocessor could be used to control the starting (Slow control) and the ramping (Fast control) of the motor. By suitable choice of the ramping components the time to ramp the motor could be known (in terms of number of pulses) and the microprocessor programmed to ensure operation within the controlled region of motor operation. In order to fully utilise the speed capabilities of the motor, the microprocessor must be programmed in machine code so that sufficient processing speed is achieved.

3.6.1 Single Motor Control

For control of one motor, output lines are used to switch the Fast, Slow and direction controls and an edge sensitive input line is used to determine the number of pulses delivered. This produces a closed loop control of the oscillator. Two counters and a timer are used to control the pulse delivery. The first counter (the index counter, IC) is used to count the number of pulses delivered. The timer times the motor acceleration and, combined with the other counter (the acceleration counter, AC), controls the point where the motor must be decelerated. This is necessary as the motor can only be stopped from the slow range of its drive without loss of position. It is assumed that if the motor is accelerated (Fast on) for a certain time then it can be decelerated (Fast off) in the same time to a speed from

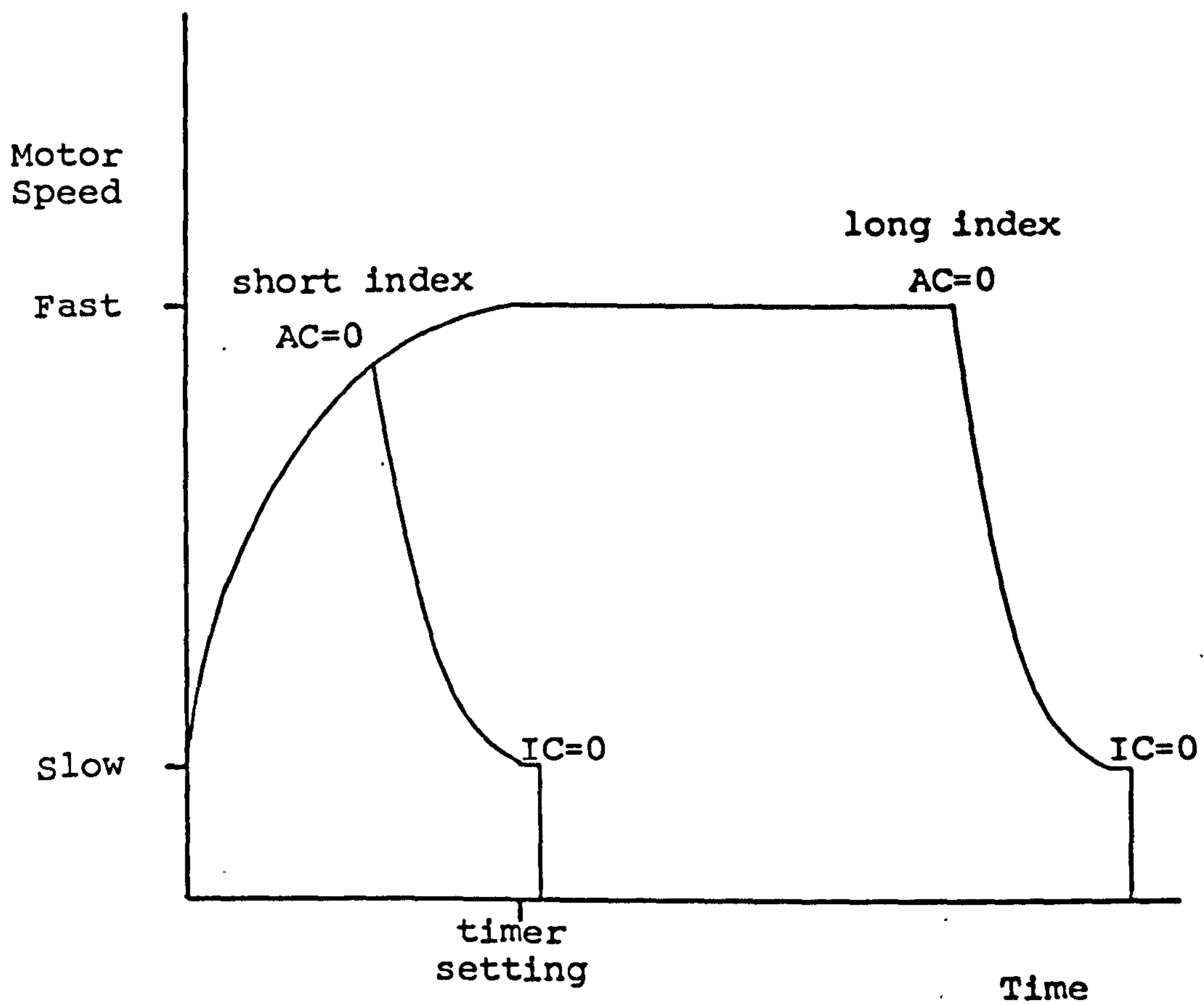


Figure 3.50 Motor control for short and long index values.

which it can be stopped. The actual form of the acceleration and deceleration is controlled using the oscillator's ramping capacitor.

During the timer period (i.e. when the timer is active) the acceleration counter (AC) is decremented from the total index (step requirement) twice for each motor step pulse. The index counter (IC) is decremented only once from the total index for each pulse delivered.

The motor drive is started by loading the counters IC and AC with the number of pulses to be delivered. The timer is loaded with the time to reach full speed. The Fast and Slow controls are taken low to start the pulse delivery and the timer is initiated. For each step pulse AC is decremented by two and IC by one. This continues until the timer times out or AC reaches zero. If AC reaches zero the motor must have been continuously accelerating and has reached half way in its step delivery. If the motor is now decelerated (Fast off) the motor should decelerate to its stop-start speed by the time IC reaches zero. If the timer times out, AC is then decremented by only one for each step, the same as IC. The motor is now running at full speed with the difference between AC and IC giving the number of pulses required to decelerate the motor. When AC reaches zero, Fast is turned off and the motor will reach the stop-start speed by the time IC reaches zero. The motor is stopped when IC reaches zero by turning Slow off. This operation is shown schematically in Figure 3.50. It can be seen that, providing the motor's acceleration and deceleration characteristics are known and the timer set accordingly, the motor's full potential can be utilised in an open loop drive without loss of position or

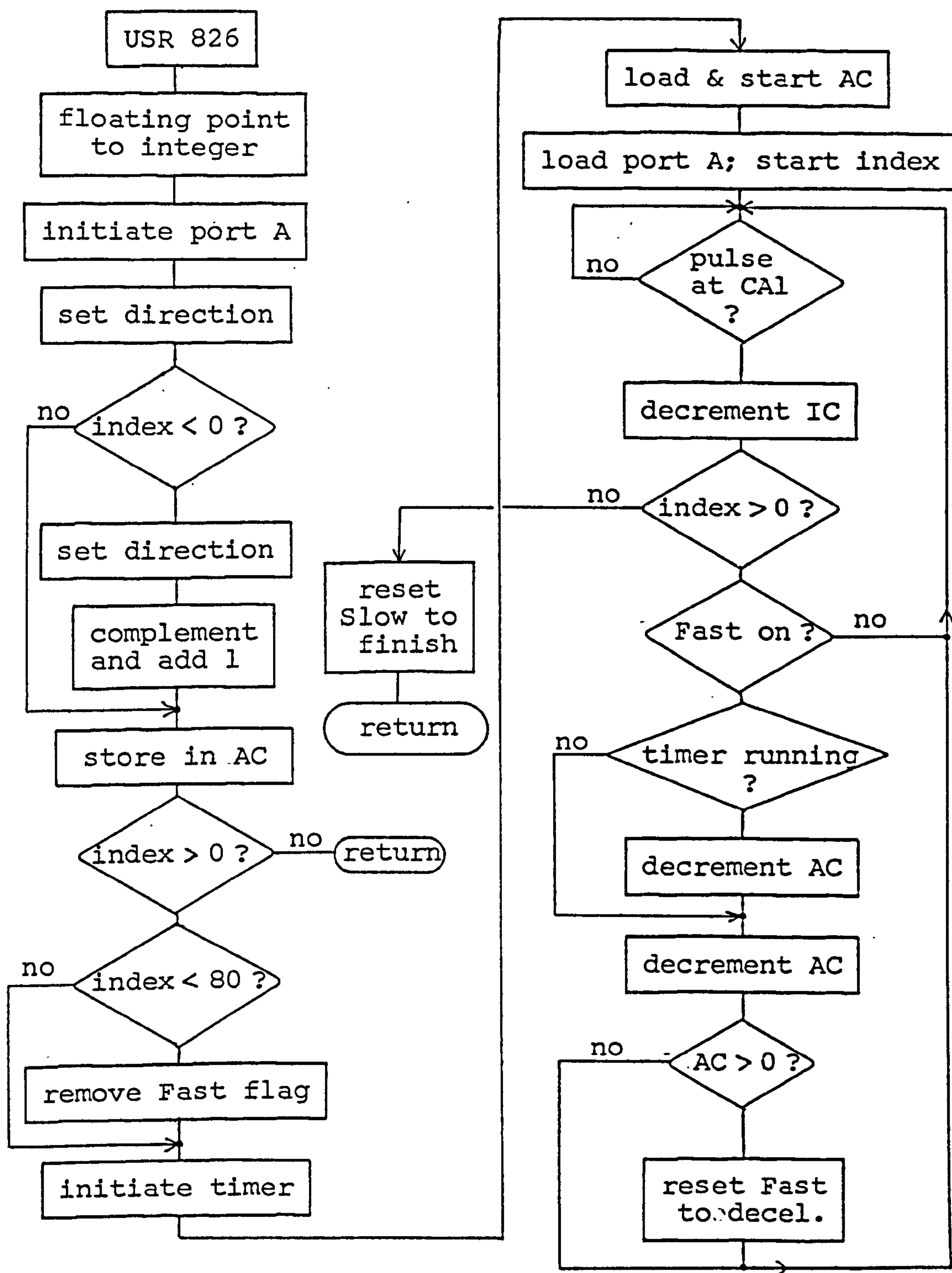


Figure 3.51 Single motor control flow chart.

synchronisation with drive pulses.

For this work the microprocessor used was an 8K Commodore Series 3000 PET. The counters are memory locations and the timer an interrupt driven counter. The 6522 VIA is used to give the timer functions, where the edge sensitive input on the CA1 line records when pulses are delivered. The port A Input/Output lines are used to control the drive board. The motor is directly controlled from a Basic program which has the number of pulses and direction fed into it. The index value is passed by means of the USR function to the machine language control section which is assembled in the second cassette buffer. By this means, and using two 8 bit memory locations to store the index values, 32767 steps can be controlled. If a negative value is passed, the 16 bit integer is complemented and 1 added to find the absolute value and the direction control is set on the drive board. The timer value must also be set into the program. A flow diagram is given for the single motor control in Figure 3.51 with the Basic program for the input given in Appendix 16.

Once the value has been passed by the USR function and the direction line set, the pulses generated are flagged by their negative edges in the 6522 IFR as CA1 transitions. The program loops on the test, awaiting a result. This gives a 7 μ s response to interrupt. The machine code listing is given in Appendix 16.

3.6.2 Dual Motor Control

In knitting operations it is rare that only one motor would be required to feed yarn. This system can be implemented to control two motors simultaneously and hence be suitable

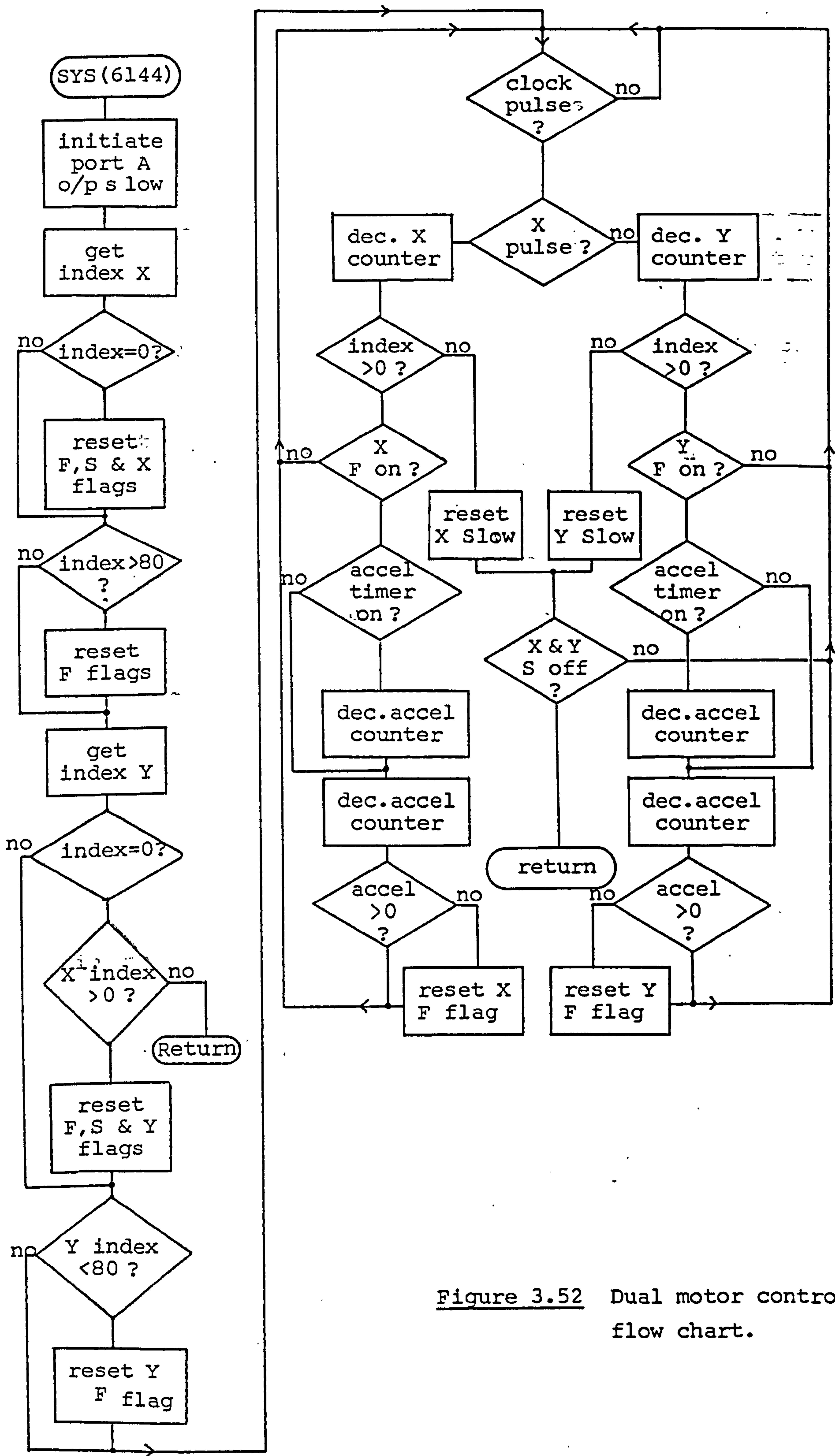


Figure 3.52 Dual motor control flow chart.

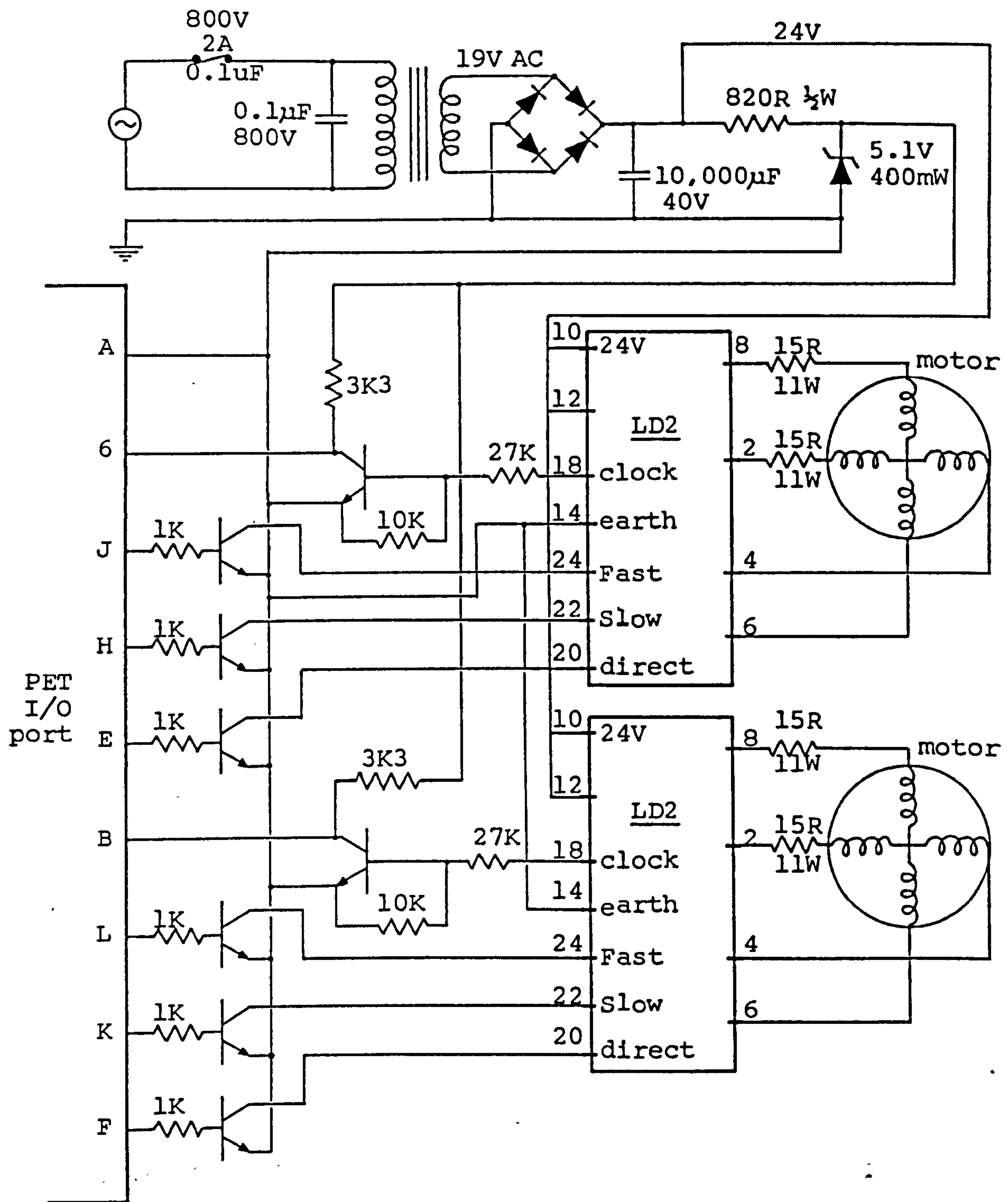


Figure 3.53 Microprocessor controlled motor drive connections.

for a double system flat bed machine. This is done using the same principle of counters and timers. The program, however, is double in size and cannot fit into the cassette buffer. The ceiling of the microprocessor RAM is lowered to 6144 bytes on the 8K processor and the program assembled above this. The USR function is not used to pass the indices as this is difficult to use for two numbers. A small Basic program is used to convert the numbers into integers and to split them into a form which can be loaded as two 8 bit numbers into memory locations. The direction flag is also set from this program. This is given in Appendix 17. The CA1 and CBI input lines are used to flag separately the movement of the two motors with the motor control lines coming from the Input/Output lines of port A. A flow diagram of the dual motor control is given in Figure 3.52 and a machine code listing in Appendix 17.

Consideration must also be given to the means of interfacing the microprocessor to the drive boards. The drive boards used are the LD2 which is all 12 V CMOS logic with a 12 V 555 oscillator with a 24 V drive to the output transistors. To make the microprocessor 5 V Input/Output port compatible, open collector transistors are used to switch the Fast, Slow and direction controls. The CA1 and CBI lines use open collector transistors again but a 5 V pull-up supply is required. This is provided by means of a 400 mW zener diode used to drop the power from the motor drive power supply. Connections are shown in Figure 3.53.

3.6.3 Knitting Considerations

The systems described can control only a limited

number of motors using a single microprocessor. They are suitable for flat bed machines where few feeds are required simultaneously.

To implement this control function on a flat machine external circuitry is required to time the start and facilities must also be offered to account for the direction of carriage movement. As when the carriage is moving towards the feed point considerably less yarn is required than when moving away from the feed point, it is possible to use the pre-set Slow speed in one direction and the pre-set Fast speed when going in the other direction. During the "turn around" of the carriage the microprocessor is not required to control the motor so this time can be used to prepare the length to be delivered. It is then passed as the feeder reaches the edge of the fabric and the motor started. To detect this point a switch is required which can enter its data on one of the input lines. The speeds need only alternate between Fast and Slow. To keep the motor on Slow the "Slow only" flag is set directly from Basic while the carriage is off the edge of the fabric.

Most flat bed machines are double system and so require two motors to be driven at the same time. This can be accommodated with a slightly modified two motor program. Some facility must be introduced to delay the start of the trailing feed. This can be an extra timer which times the required delay before starting the appropriate motor. This will lengthen the program but not excessively.

As many flat bed machines are now provided with a microprocessor which holds the needle selection data, this data can be used to control the length of yarn to be delivered.

The full course length feed system can be used to deliver a known amount of yarn at a constant speed for each course. With a plain or small repeat fabric the actual speed at which the yarn is required in the fabric is relatively constant, as shown by the acceptance of the trip-tape feed on circular machines. It is then possible to analyse the pattern to get the yarn requirements, determine which way the carriage is going to move, calculate the yarn feed length and speed, pre-set the speed on the oscillator then pass the length to the program at the required time. Here it must be possible to select speeds over a wide range. The 555 ramped oscillator in a programmable mode is suitable, switching various resistances into the control section. Alternatively the 2240 programmable oscillator can be used. With the programmable oscillator the ramping function must be programmed into its operation. As each pulse is counted the oscillator frequency can be increased until the pre-set speed is reached. A similar deceleration ramp can also be introduced.

It will be necessary to set the knitting machine so that the length of yarn presented will all be knitted into the fabric. This may not always be possible with a constant speed feed operating for a full course. The machine, even for plain fabrics, must have cams and take-up adjusted to take in just the right amount of yarn on each course. Any errors here will be additive.

The knitting process is fairly versatile and does in fact tend to "self adjust". This is due to knitting being a balance between input and output tensions. When too much yarn is fed, input tension drops and the balance point within the knitting zone shifts, causing longer loops to be drawn. In

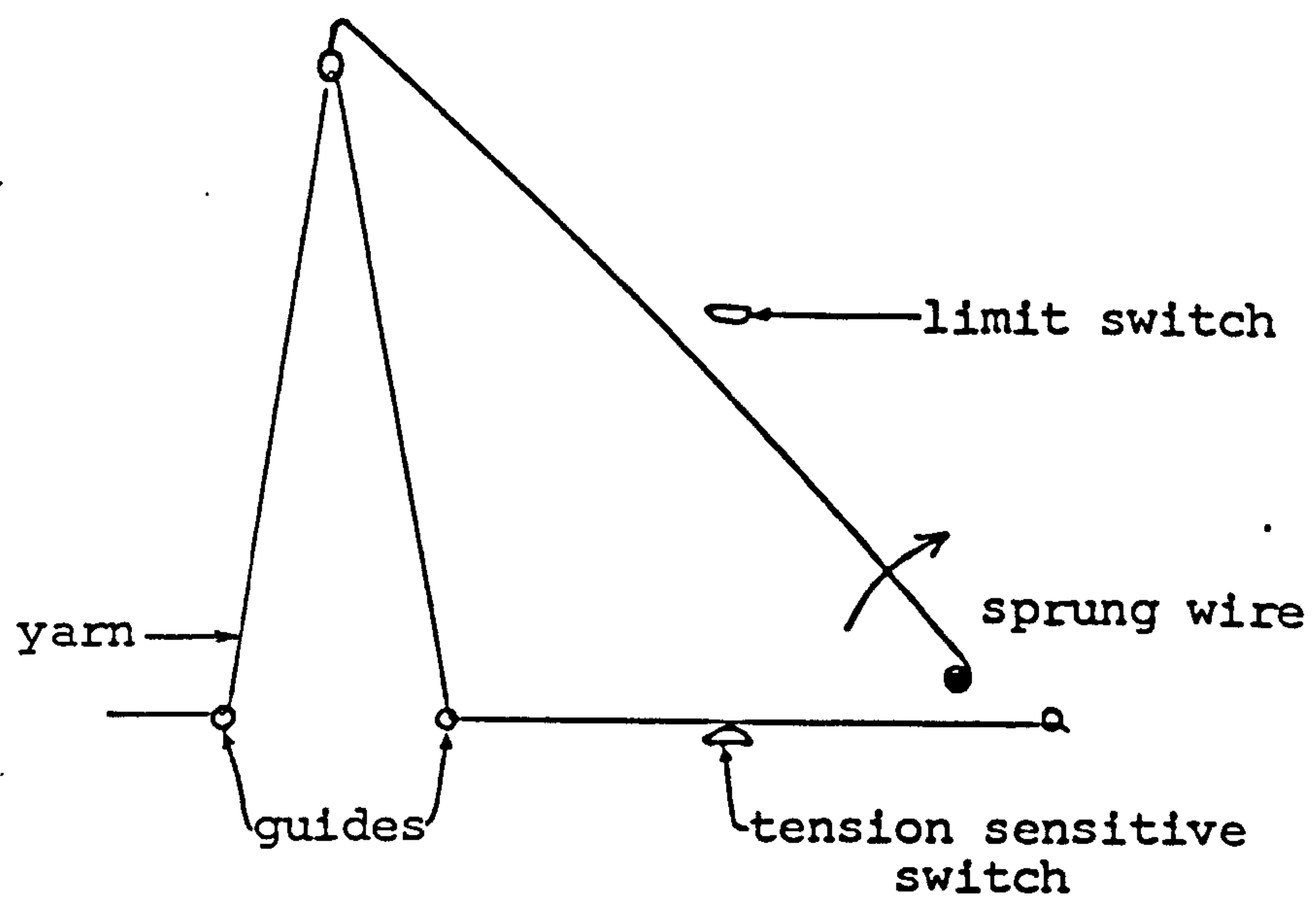


Figure 3.54 Means of introducing length limits to control feed.

the reverse case an increase in tension will result in smaller loops. This "self adjustment" however is severely limited, particularly in the case where widely varying demand rates due to needle selection are required in different parts of the fabric. The skill of the knitting mechanic will determine the success of this type of system. If however the only guides to the quality of the fabric are considered to be the unroving of courses or the appearance on the machine this method can be seen to give a positive indication of whether the correct amount of yarn is entering the fabric.

This setting up success can be monitored by a storage device such as at present used to account for changes in direction of carriage movement. This is shown in Figure 3.54. The limits of the device are set to correspond to the acceptable feed length error. One switch, which detects when too much yarn is fed, is placed so as to be triggered by excessive upward movement of the spring element. A tension sensitive device is triggered by the yarn tension when too little yarn is fed.

Without positive feed a similar system can be used for setting up the machine. The length fed per course can be monitored and then examined to determine if the settings are correct. As long as the pattern is known and can be analysed to give the correct length for each course, this need only be adjusted for carriage movement and compared with the length delivered. Adjustments can then be made to the machine settings as appropriate. If a free running wheel is driven by the yarn its movement can be detected optically or electronically and recorded by a simple counter. Thus a

very cheap system can be set up and can also be used to monitor complete yarn usage etc.

Positive delivery of the yarn for patterned fabric could be incorporated with a storage device to reduce the problems of a constant speed feed. The needs of each course could be fed into a storage device (such as the IRO) which is driven by a stepper motor. The microprocessor is used to analyse the pattern and then present the prepared course to the storage device. The delivery speed must be fast (i.e. less than one traverse time) and time is allowed for simultaneous pattern analysis and feed control by the microprocessor. Some detection should be incorporated to ensure that the correct amount of yarn is knitted. As a storage element will essentially feed the yarn at a constant tension no "self adjustment" in the knitting process can occur and the machine settings will be extremely critical.

It is obviously better to provide a system which is much more closely linked to yarn demands. Both the 555 ramped oscillator and the programmable oscillator offer switching which can be used to switch the speeds after a given number of pulses are delivered. If the system is to be microprocessor controlled however, it is probably better to generate the motor pulses in the microprocessor.

3.6.4 Pulse Generation from the Parallel In, Serial Out Register

As mentioned in section 3.4.5.2 the 6522 possesses a parallel in, serial out register which has a counter controlled shift out rate. This can be used to vary the pulse rates between courses or within courses while still knowing the number of pulses delivered. As this register can operate in

a free running mode independent of the other microprocessor functions, this can be used while the microprocessor simultaneously carries out other work, interrupting only to stop and start the pulse train.

These systems described have all concentrated on limiting the circuitry required outside the microprocessor and so have not linked the delivery rate to the actual knitting machine. As much as possible of the control is from software, making change very simple and linking with data analysis quite easy. However, when it comes to needle to needle selections the data is already present as a needle selection, so the processing functions are not necessary.

By feeding to a small repeat element within the fabric instead of to a whole course timing problems can be considerably reduced. As has been seen in previous chapters jacquard fabrics produced with a bird's eye or other small repeat backing can be broken down into fairly small repeat elements. For the bird's eye this distance is the length between the two successive dial needles.

If the pattern information is stored in a microprocessor it can be analysed in terms of this repeat unit. On electronic needle selection machines this data can be extracted and used as the needles are selected. On circular machines the selection occurs at the start of the knitting zone and so some method of preserving the data until the needle reaches the knock over point is required. This would entail storing the information for up to 18 cycles. The data would be input as 00, 01, 10 and 11 needle selections on the cylinder. Some type of shift register could be used to store the data,

Shift clock - shift one place right for
each needle on cylinder

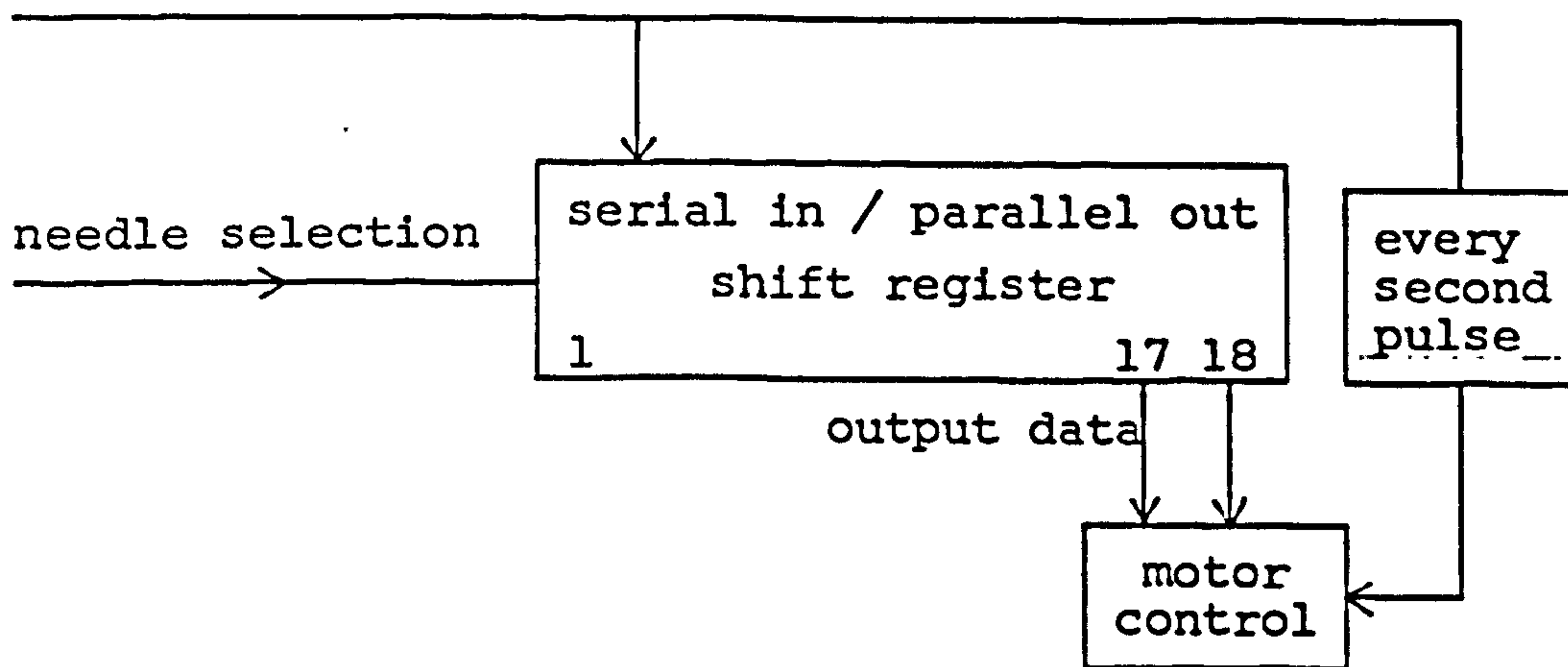


Figure 3.55 Schematic data delay storage system for a circular machine with information derived from electronic needle selection. 302.

gradually shifting it along the line until it is required. This is shown schematically in Figure 3.55. Here the needle selection data is shifted under the control of a clock pulse linked to each needle and then taken out every two needle selections after the delay.

On electronic flat bed machines however the needle selection data is laid out by the trailing cam. Here then the data storage length will be either the distance between the leading and trailing systems or the whole course laid out in reverse. This requires considerable storage space plus processing to obtain the required format for length feed. Virtually another microprocessor would be needed to control these functions.

3.7 Motor Small Cycle Performance

Before considering the feed to small repeat lengths, it is necessary to examine the performance of the stepper motors over the small cycles required.

The most important parameters for the motor's small cycle performance are the speed at which it can be instantly started, the acceleration rate and the maximum speed. All these parameters will be functions of the load applied to the system. The cycle time required for knitting performance is in the vicinity of 6 ms (see section 2.1). If motor control is to be maintained the motor must be able to accelerate from the stop-start speed to full speed and decelerate back again within this time period.

The data presented in section 3.2.7 showed the maximum stop-start speed and the maximum slewing rate for a given motor with a given drive. Manufacturer's details also give

the effect of load added onto the motor rotor¹⁷². From these it should be possible to derive the motor's small cycle performance. The equation for rotary motion

$$T = 2Ia \times 10^{-5}$$

where T = torque to accelerate (gcm^2)
 I = total inertial load (gcm)
 a = angular acceleration (rads^{-2})

must be transferred into a form suitable for the stepper motor. For a 200 step per revolution motor this can be written in the form

$$T = \frac{4\pi I w'}{t} \times 10^{-5}$$

assuming constant acceleration.

with w' = change in steps/s

t = time over which this change occurs (s).

For the 20-2215D200-E1.5 with a 24 V unipolar drive an unloaded maximum stop-start rate of 1,200 steps/s is quoted. Here the only load on the motor is the inertia of its own rotor (60 gcm^2). The calculated torque required to accelerate to this speed in one step is 8 kgcm or 4 kgcm for two completed steps (which gives one step at the desired rate). The maximum torque quoted for this motor, however, is only 1.5 kgcm, so the situation would seem impossible. Either the motor performance is much lower than quoted or the stepper motor does not behave according to the simplified constant torque, constant acceleration arrangement.

This is also true for the value of performance under load. A stop-start performance of 900 steps/s is quoted for this motor under an additional inertial load of 110 gcm^2 . Such a load would require a calculated torque of 14.6 kgcm,

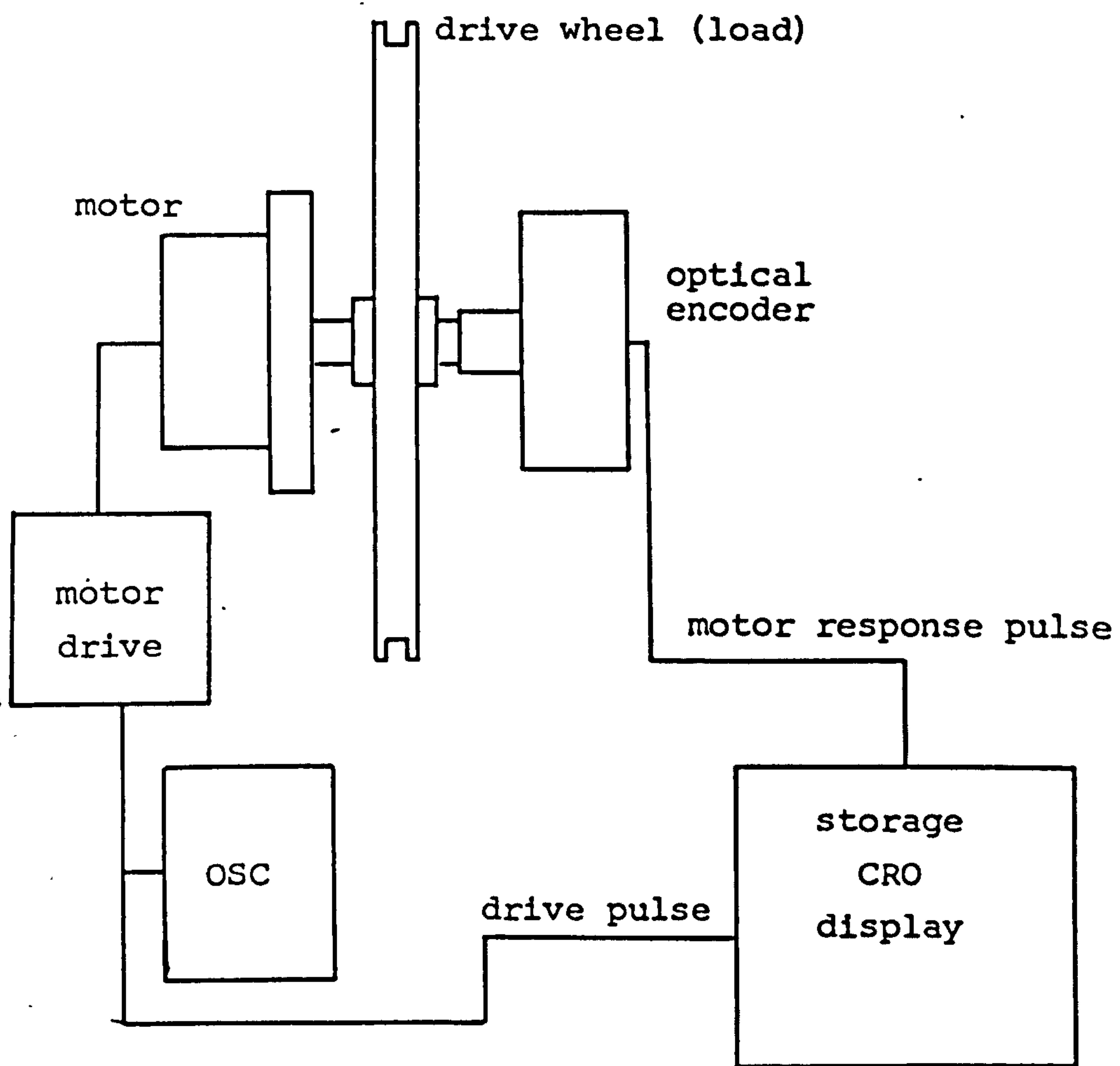


Figure 3.56 Schematic diagram of the arrangement used for measuring motor small cycle performance.

which is even further outside the motor's range. Obviously an actual measurement must be taken on the motor to determine its performance.

To measure the motor's performance an optical shaft encoder²⁰⁰ was attached to the motor's shaft. A pulse train was applied to the motor using the appropriate drive board and its ability to match this train was measured by means of a storage oscilloscope. This is shown schematically in Figure 3.56. The additional inertial load of the encoder was only 10 gcm² so this arrangement could give the motor's unloaded stop-start performance. To measure the acceleration rate of the motor, it was set running at the maximum stop-start rate (by bringing the Slow control to ground) and then the Fast control was brought to ground. The time to accelerate to Fast was examined by means of the optical encoder and the storage oscilloscope to see if it matched the applied pulse train. The ramping capacitor was adjusted on the drive board to gain the maximum ramping slope which could be followed under these conditions.

A cork filled drive wheel was introduced to simulate the motor's performance when driving a yarn. This wheel was 64 mm diameter which gives a single step of 1 mm at 200 steps per revolution. This wheel was attached to the motor drive shaft by means of a metal boss with a screw on tapered locking device. The basic inertia equation is

$$I = W (r_1^2 + r_2^2) / 2$$

where W is the mass in grammes, and r_1 and r_2 are the inside and outside radii of a cylinder in cm. This reduces to

$$I = Wr^2 / 2 \quad \text{for a disc of radius } r.$$

The inertia of the load system was determined as:

5.9 gcm² for the boss.

26.2 gcm² for the disc.

An additional inertial load of 90 gcm², as would be applied by a yarn with a 10 g input tension, was added. This gave a total load inertia of roughly 120 gcm². The performance of the three motor drive combinations could now be examined for both the stop-start performance and, more importantly, the number of pulses which can be delivered in 6 ms.

For the 20-2215D200-E1.5 motor driven from a 053/1 24 V unipolar drive the quoted stop-start value of 1,200 steps/s was achieved without additional load. With the additional load 900 steps/s was achieved. It would thus seem that the quoted performance is correct and so the stepper motor cannot be considered to perform as expected for standard rotary motion. Here, as in all later cases, the lowest rate achieved is quoted as the motor exhibits some differences in performance with position due to the effect of the "ghost" poles.

The unloaded 20-2215D200-E1.5 motor could accelerate from 1,200 to 3,000 steps/s in 2 ms and decelerate back to 1,200 steps/s in 1.4 ms maintaining control of the motor. With a 6 ms cycle 13 pulses could be delivered. Here the deceleration time must be less than the acceleration time because of the asymmetrical ramps produced by the 555 ramping oscillator system. Under load conditions the motor could be accelerated from 900 to 2,500 steps/s in 2.7 ms and decelerated in 1.8 ms. In a 6 ms cycle 9 pulses were delivered.

Tests were also carried out with the motor microstepping at 400 steps per revolution. Here approximately twice the

Table 3.3

Motor performance over a small cycle.

Motor	Load (gcm ²)	Set Speeds (1 mm steps/s)		Accel. Time (ms)	Decel. Time (ms)	No. of 1mm Steps/6ms
		Slow	Fast			
20-2215D200-E1.5	0	1200	3000	2.0	1.4	13
	110	900	2500	2.7	1.9	9
	200	800	2300	3.0	2.2	8
17-2220D200-E033 at 400 steps/rev	0	1600	3000	1.3	1.0	17
	110	1000	3000	2.2	1.7	14
	0	1600	6000	2.0	1.4	22
	110	1000	5000	2.5	1.9	18
20-2220D200-E5.1 at 400 steps/rev	0	600	1100	3.6	2.4	6
	110	600	1100	3.6	2.4	6
	500	600	2500	7.6	4.2	14/12ms

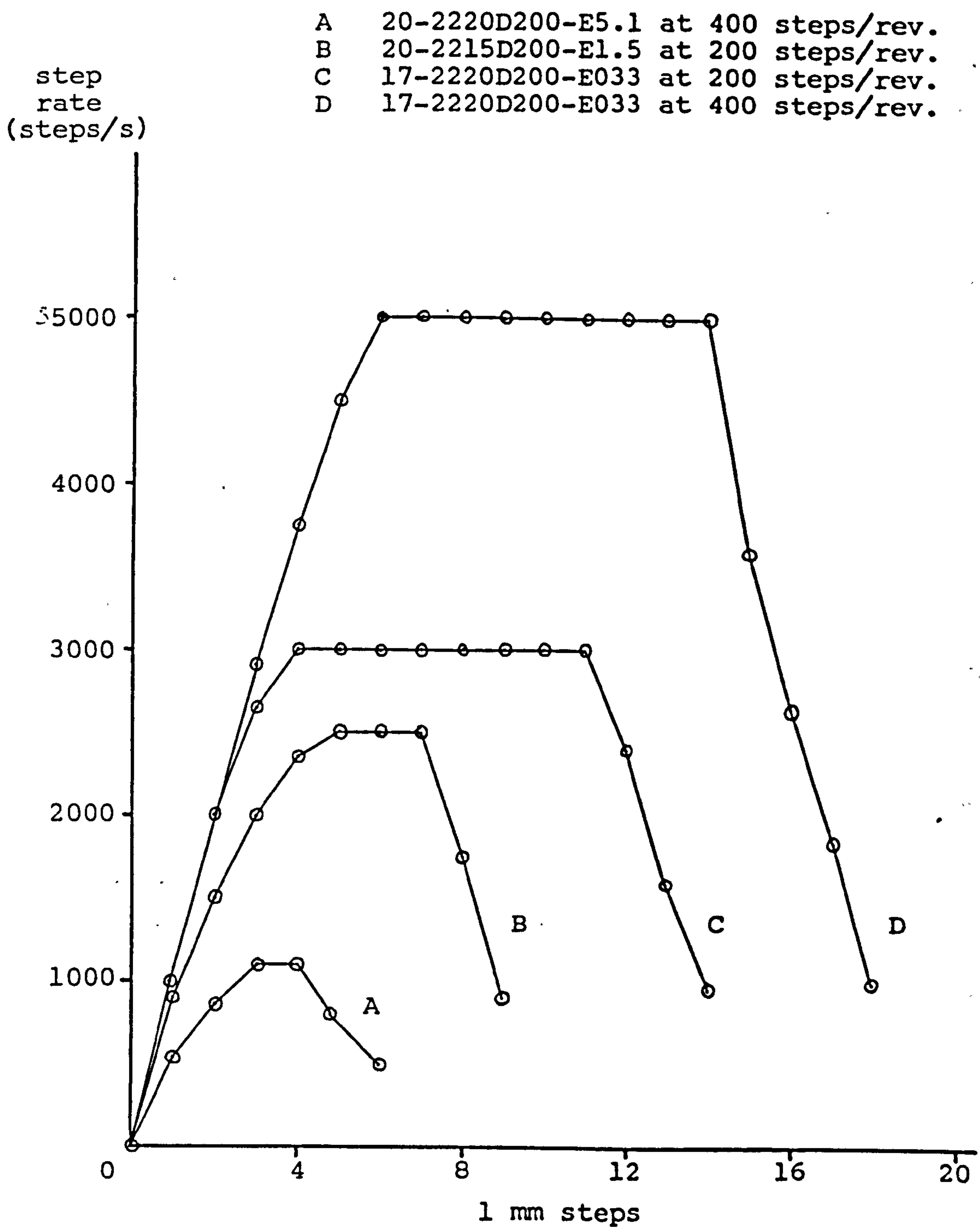


Figure 3.57 Number of 1 mm steps which can be taken in 6 ms with an inertial load of 110 gcm^2 showing the actual step rate of each step.

performance was achieved i.e. twice the number of steps were delivered but at half the step distance.

Similar tests were carried out on the 17-2220D200-E033 motor with the 053/1 24 V unipolar drive and on the 20-2220D200-E5.1 motor with the LD2 24 V bipolar drive. Results are tabulated for the three motor drive arrangements in Table 3.3 and given graphically in Figure 3.57.

For the 17-2220D200-E033 a resonance range exists between 3,000 and 5,000 steps/s in the full step mode. However by microstepping the motor at 400 steps per revolution the motor can be run in this range. Here, for comparison, the results are quoted for equivalent performance in the full step range. This motor's performance drops markedly with applied load.

The 20-2220D200-E5.1 motor was also run at 400 steps per revolution and equivalent results at 200 steps per revolution are given. Here it is shown how this motor cannot accelerate quickly but does produce high starting torque, being relatively unaffected by the applied load. This motor was also tested with a much higher drive load (500 gcm^2) and allowed to accelerate more slowly to achieve a speed of 2,500 steps/s and return to the stop-start curve in 12 ms. While not suitable for very short cycle high speed work the torque of this motor is very good.

The approximate maximum length requirements on an 18 gge circular jacquard at this speed would be about 14 mm. The 17-2220D200-E033 could be used comfortably to drive this amount of yarn in 6 ms. The performance of the 20-2215D200-E1.5 borders on this amount while the 20-2220D200-E5.1 is not suitable for this type of stop start drive. To use the

20-2215D200-E1.5 motor to perform in this manner required a larger drive wheel of 50% greater radius. Here the torque requirements were also increased. Under this increase of load (to 200 gcm²) the motor stop-start speed was reduced to 800 steps/s and the maximum speed to 2300 steps/s and eight pulses were delivered in the 6 ms cycle. If this motor is used yarn tensions would need to be kept to 10 g or less which is possible.

3.8 Hardware Control Systems

The microprocessor is a very versatile device. It is ideal for developing systems and examining methods of approach, as it can easily be changed by means of software. However for reasons of cost it is not ideal for duplicating the systems discussed for any number of motors. It is preferable to produce a hardware control system. The following hardware systems are developed using TTL logic circuitry but could easily be developed using CMOS if the lower power requirement is considered important. Because the power for driving the motors is so much higher than needed to drive the logic, this has not been considered here.

3.8.1 External

The system where the 555 ramped oscillator is controlled through a closed loop using the microprocessor can be quite easily duplicated using hardware. Two counters can again be used to control the number of pulses delivered with Fast and Slow controls on respectively. A frequency doubler is used to double the number of pulses taken from the Fast control counter for each pulse delivered during acceleration,

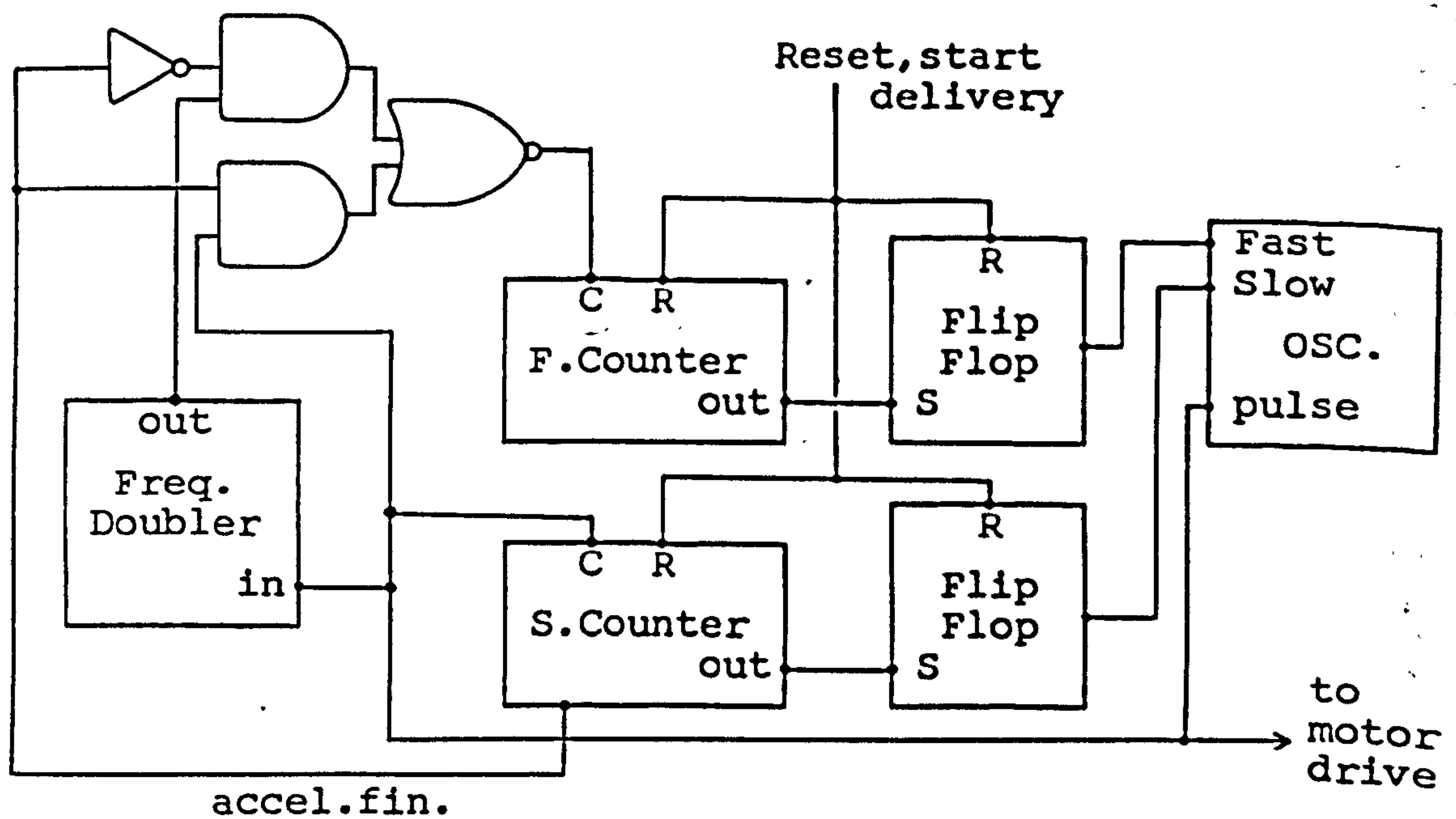


Figure 3.58 Closed loop oscillator control using a frequency doubler.

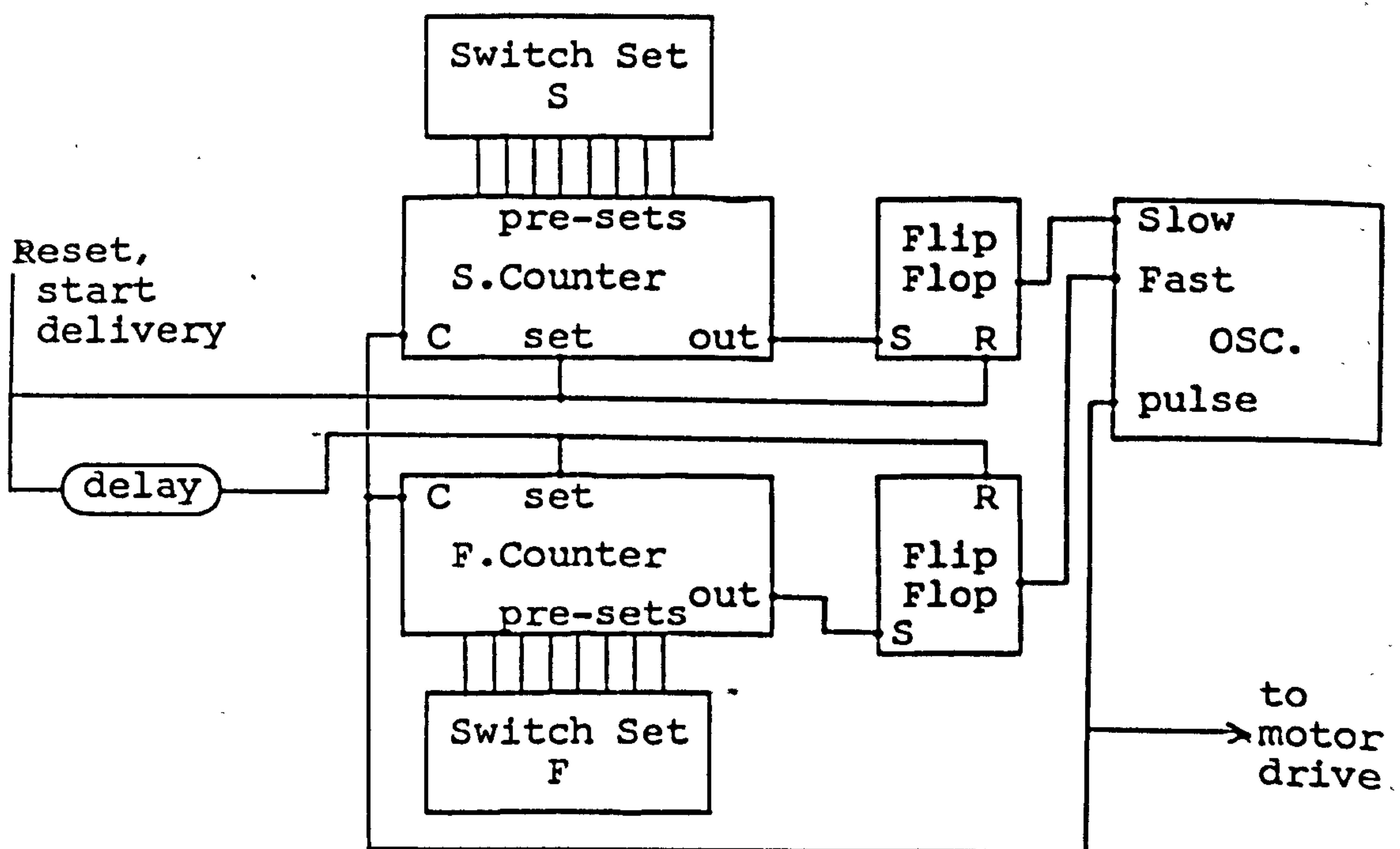


Figure 3.59 Closed loop oscillator control using pre-set counters with time delay.

while each pulse reduces the Slow control counter by one. The time for which the frequency doubler counts into the Fast control counter is pre-set on the Slow control counter as the number of pulses required to accelerate the motor. The output is controlled by two pre-settable flip-flops. This system is shown schematically in Figure 3.58 with the actual circuit shown in Appendix 18. Again both Slow and Fast controls are turned on simultaneously. As found previously, to optimise the small cycle performance a time delay of one pulse must be introduced between when the Slow and Fast controls are turned on. Thus maximum acceleration of the motor can be achieved. When feeding a large number of pulses this is not necessary but for a small cycle control it becomes critical.

Because the monostables used for the frequency doubling are rather unstable elements it is thought better to use two pre-settable counters which enable the number of pulses for Fast on to be set relative to the total number of pulses required. This is shown schematically in Figure 3.59 and the actual circuit is given in Appendix 18. Only 10 packages are needed to produce up to 256 pulses and the system can easily be extended by adding to the counters. This is an extremely cheap and small system. Thus for each motor it is quite possible to produce an individually controlled drive board.

This system would seem ideal for flat bed feed producing simple structures. Here the cycle times can be reduced from the full width as considered previously to a suitable small section within the fabric, driven perhaps from the carriage drive and so eliminating timing and

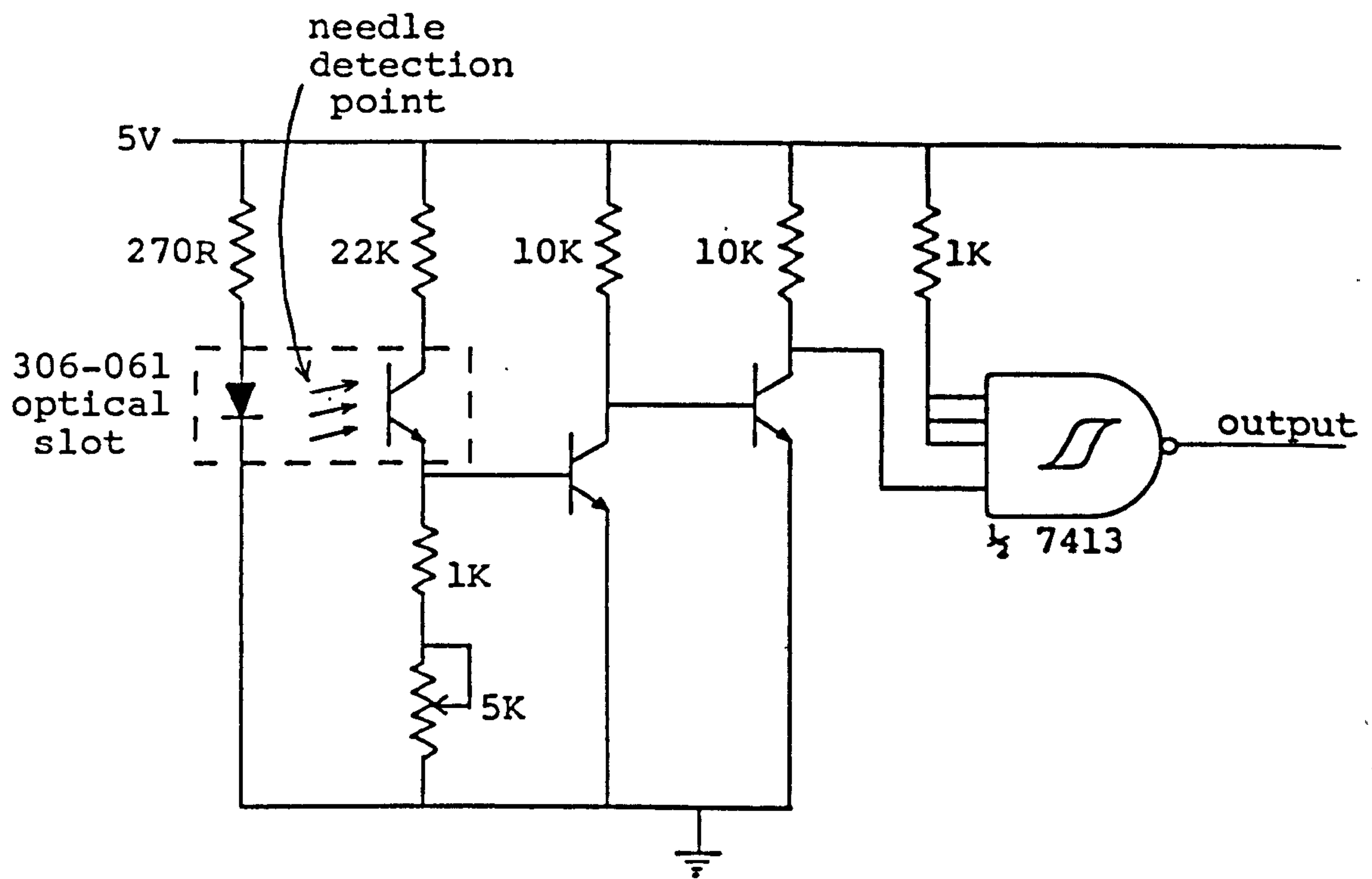


Figure 3.60 Optical needle detection circuit.

stoppage problems. This however is not suitable for patterned fabric. While it is possible to externally set the counters this would require accurate synchronisation with the needles to be successful.

3.8.2 Needle Selection

To produce a full jacquard yarn feed system which can be used on the maximum number of machines it is desirable that selection can be achieved from the common element in all these machines; that is, the needles. Two main methods of needle detection are possible: optical^{201,202} and magnetic²⁰³. The optical system has been used here because of its simplicity and low cost. The needle detection circuit is shown in Figure 3.60. The needle passes through an infra-red beam between a light emitting diode and a phototransistor. These components are a spectrally matched pair. The circuit is sufficiently sensitive to be able to detect 18 gge needles on a circular machine running at 20 rpm. However the optical slot used is rather bulky and in many of the commercial applications a discrete component version²⁰¹ which may be mounted directly on the feeder should be used.

3.8.2.1 Toggling

The cycle used for basic control purposes is determined by the selection of a dial needle at a single feed. As previously discussed for a bird's eye backed jacquard between this and the next dial needle selected either 0, 1 or 2 cylinder needles are selected. It is required to input which of these occurs and then to use this information to

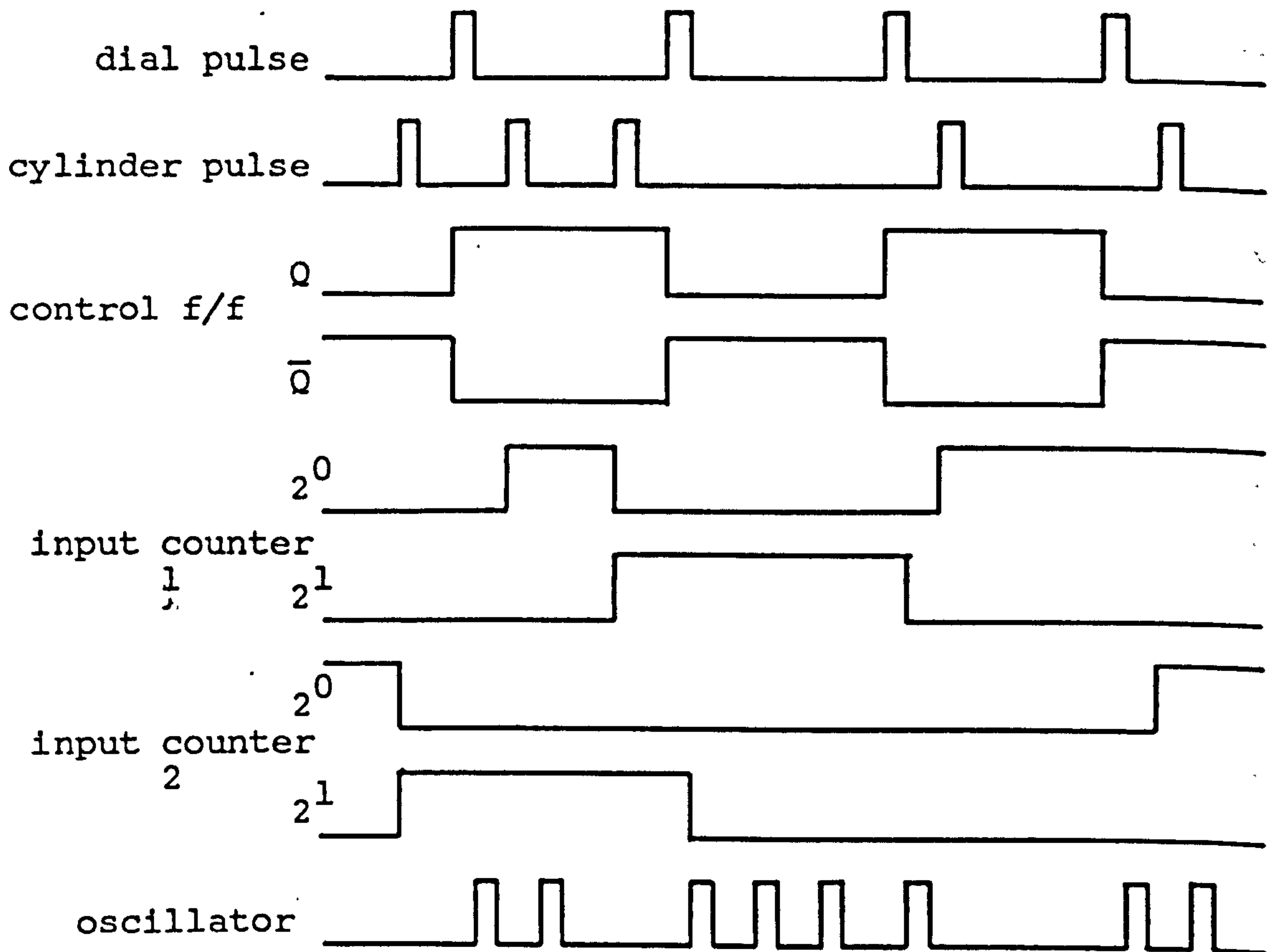


Figure 3.61 The first two lines show pulse input from detection of dial and cylinder needles as they pass a point one cycle before the feed. The oscillator output is then matched to the output count one cycle previously.

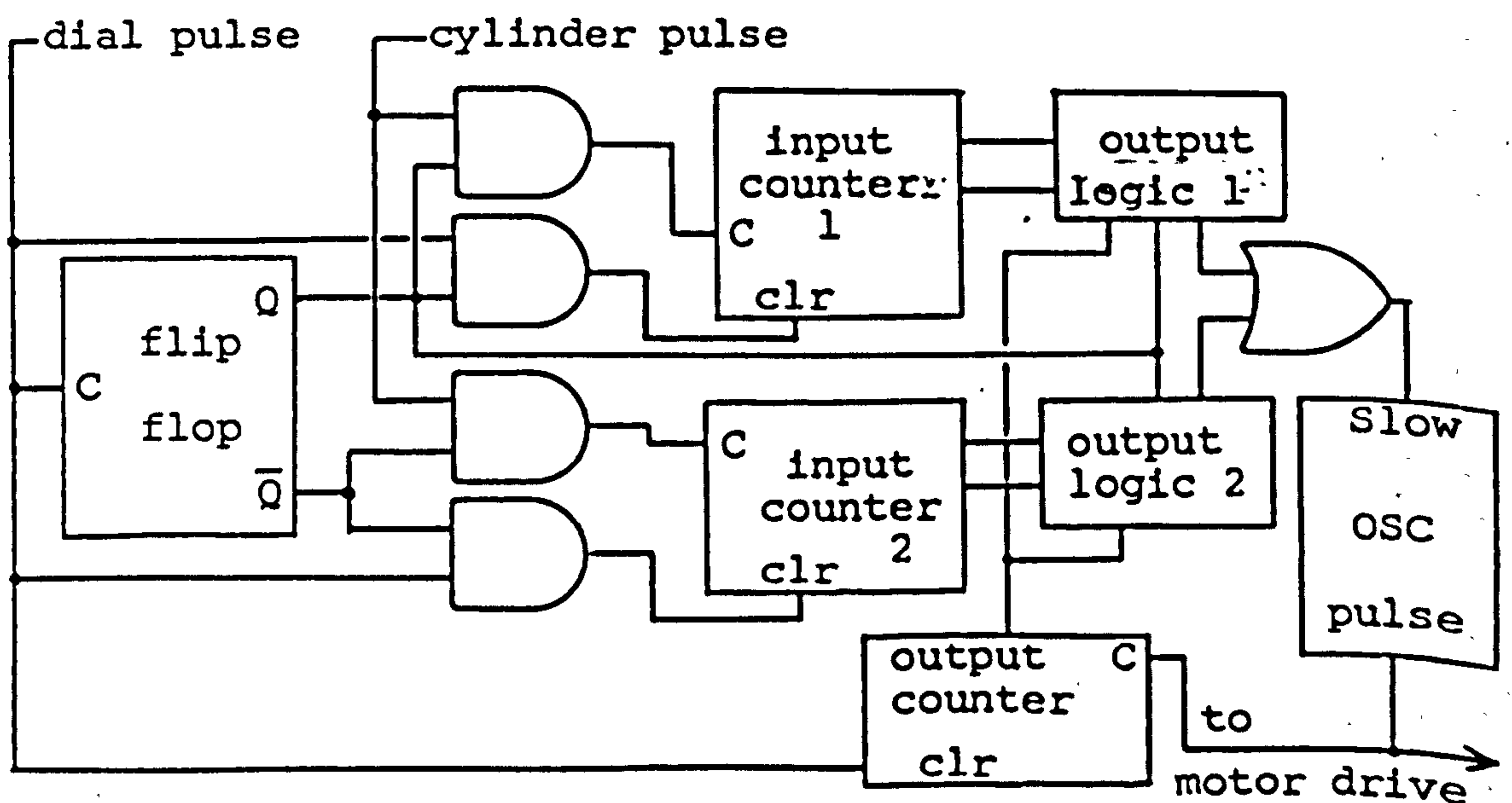


Figure 3.62 Schematic toggling circuit to control an oscillator.

drive the yarn when this unit enters the feed zone. It is proposed that the selection be made one cycle before the feed zone. This is shown schematically on Figure 3.61. As the dial needle passes the detection point it enables the cylinder needle information to be input until the next dial needle passes. When this second dial needle passes the information is then used to control the motor drive and, through closed loop control on the oscillator, deliver the required number of pulses. This then toggles with the dial needles between detection of cylinder needles and control of the motor. If a second system is introduced which behaves in the same manner but alternates its input and control sections with the first the motor can be controlled over each cycle.

To implement the control a single flip-flop is used toggling with the dial needle pulse train. This alternates the input stages of two 2 bit counters which are used to store the cylinder needle selections. Through an output selection network the control of the motor is alternated between these two input counters to deliver one of three pre-set numbers of pulses. The function of this control system can be seen from the timing diagram in Figure 3.61. A schematic form of the circuit is shown in Figure 3.62 with the actual circuit shown in Appendix 19. Here JK flip-flops are used as the control selector and the 2 bit counters. The output logic is a series of AND, NAND, INVERTOR and OR gates which selects either 1, 2 or 3 pulses to be delivered to the motor. The output count number can easily be changed by connections on the counter. A 4 bit counter is used to control the output so selection of up to 16

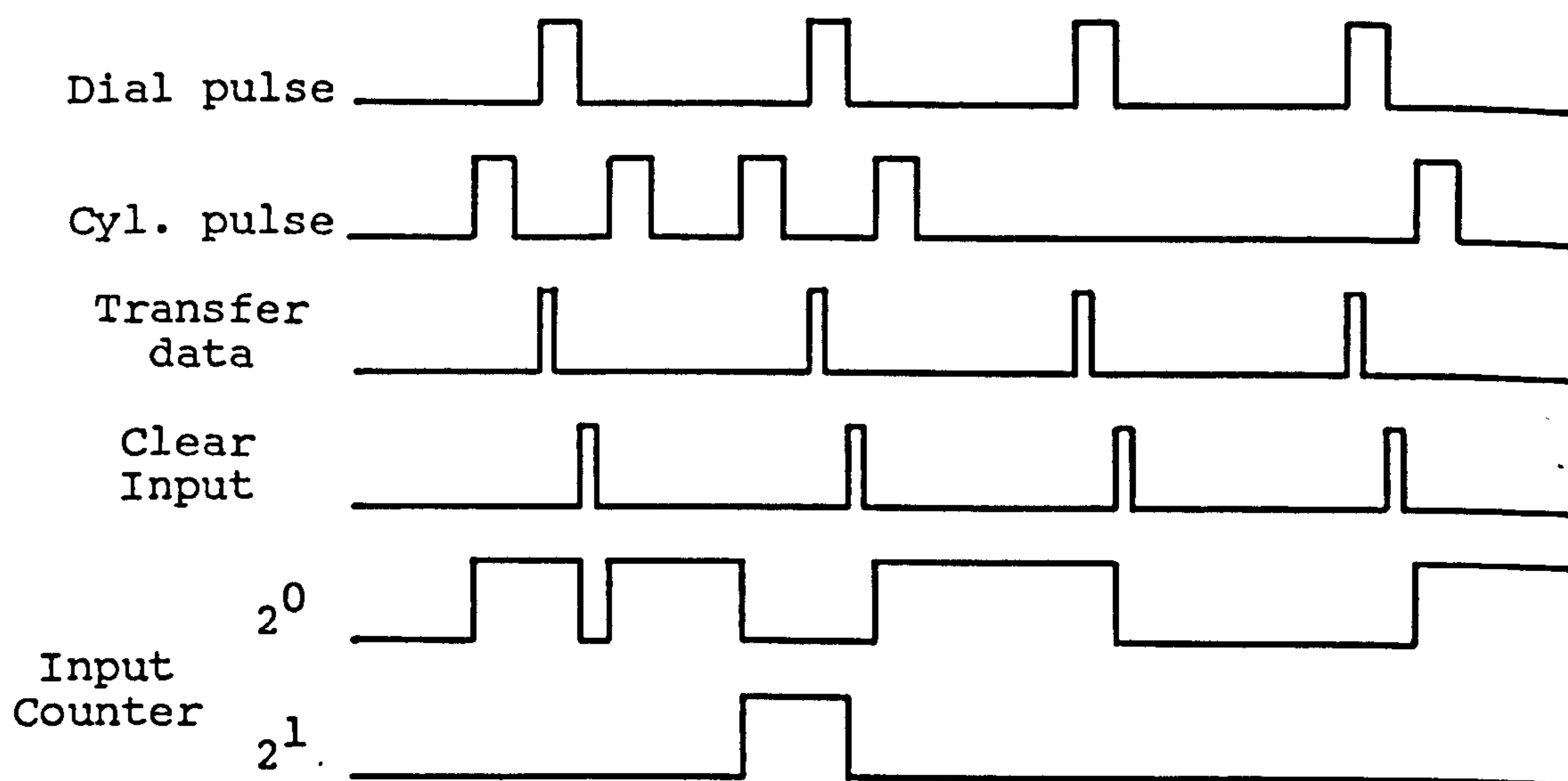


Figure 3.63 Timing with a single input counter.

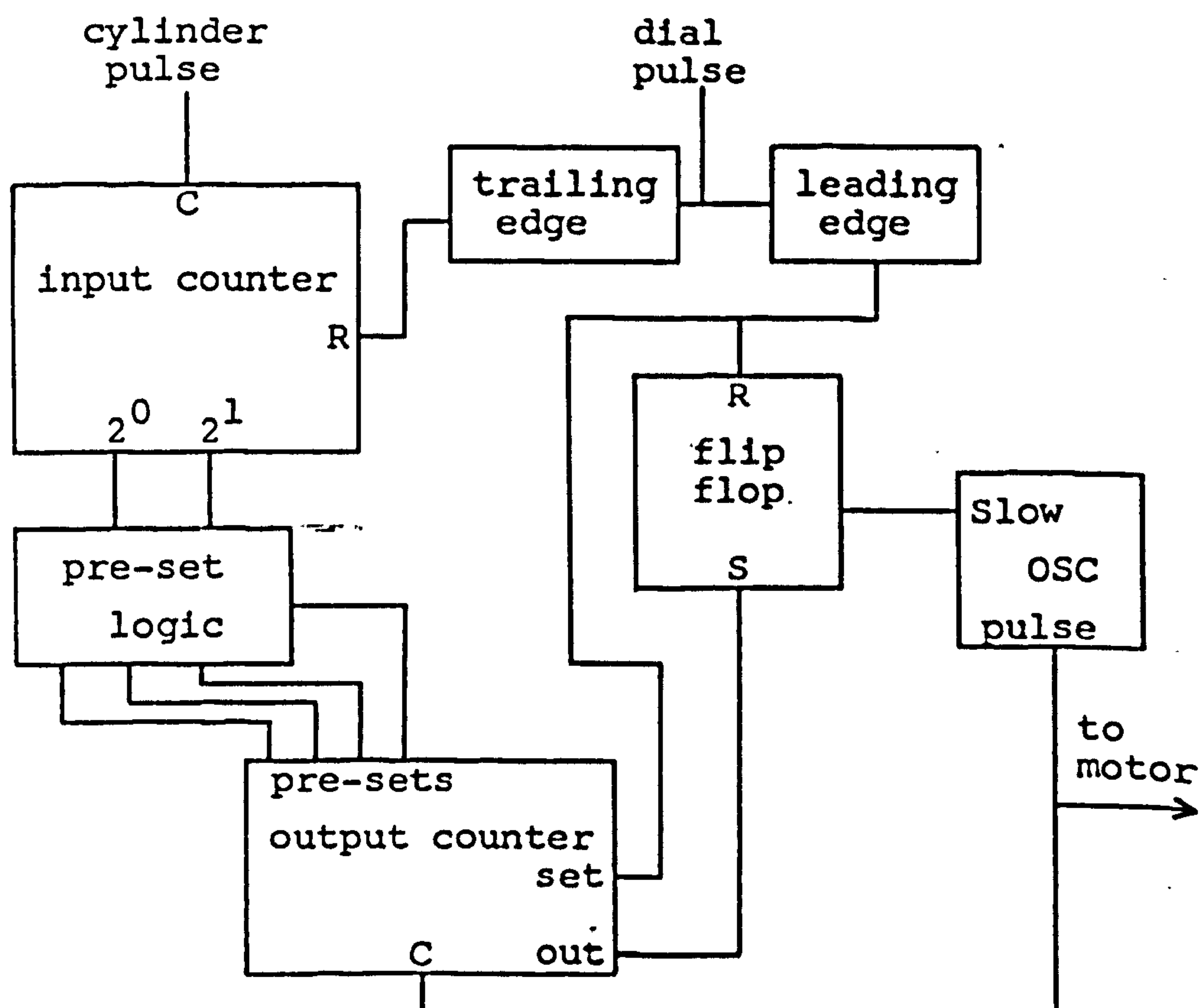


Figure 3.64 Schematic circuit using a single input stage with a pre-settable counter.

Input		Output				Inverter Inputs			
A	B	a	b	c	d	\bar{a}	\bar{b}	\bar{c}	\bar{d}
0	0	0	0	1	0	1	1	0	1
1	0	0	1	1	0	1	0	0	1
0	1	0	0	0	1	1	1	1	0
						1	\bar{A}	B	\bar{B}

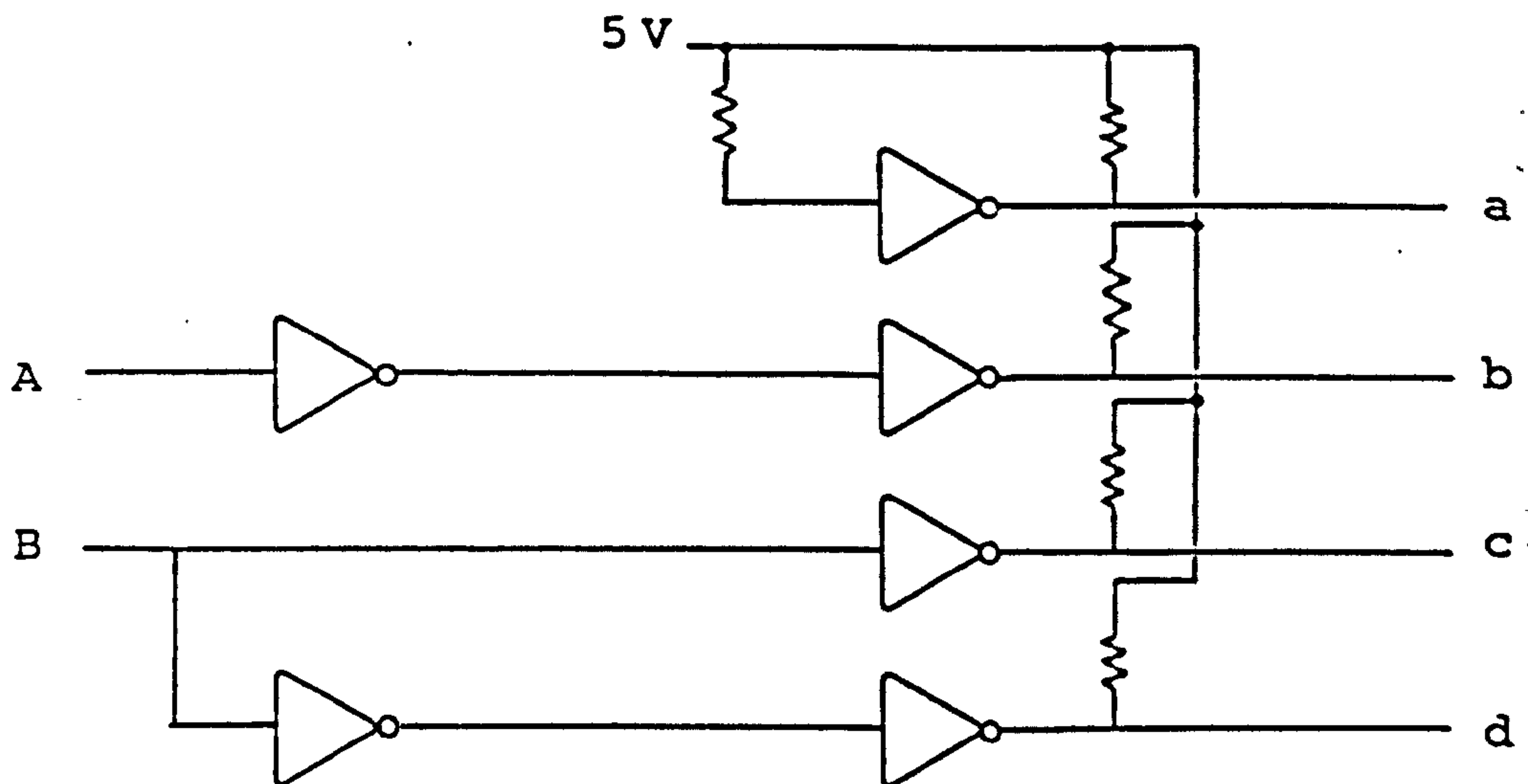


Figure 3.65 Pre-set logic truth table and circuit connections. A and B are binary weighted input counter outputs and a, b, c and d are binary weighted pre-set inputs.

pulses can be obtained.

This system requires 11 standard TTL packages and 3 transistors and controls the oscillator only in the stop-start range of the motor.

3.8.2.2 Timing

One of the limitations of the toggling system with its dual input stage is that rather a lot of logic is required to control the selection of the output stages. If only one input stage is used the timing of the system must be altered. With timing of the type shown in Figure 3.63 it is possible to reduce the complexity of the switching. Here two monostables are introduced to derive pulses from the leading and trailing edges of the dial pulse. Only one input counter is used. The leading edge pulse transfers the data already on the input counter to the output stage while the trailing edge pulse is used to clear the counter. Any type of switched transfer can be used and so any time delay can be built into this circuit.

Here also it is proposed that a pre-settable counter be used and through a pre-set logic arrangement the required number of pulses to be delivered are placed onto the counter. This counter counts down and acts as a closed loop control on the motor drive oscillator to deliver the required number of pulses. The circuit is shown schematically Figure 3.64.

Figure 3.65 shows how the input count selections can be used to pre-set the counter to 4, 6 or 8 pulses for the three input selections respectively. Open collector output buffers are used with a 5 V pull-up to switch on the pre-set inputs of the 4 bit counter. In a similar manner the two

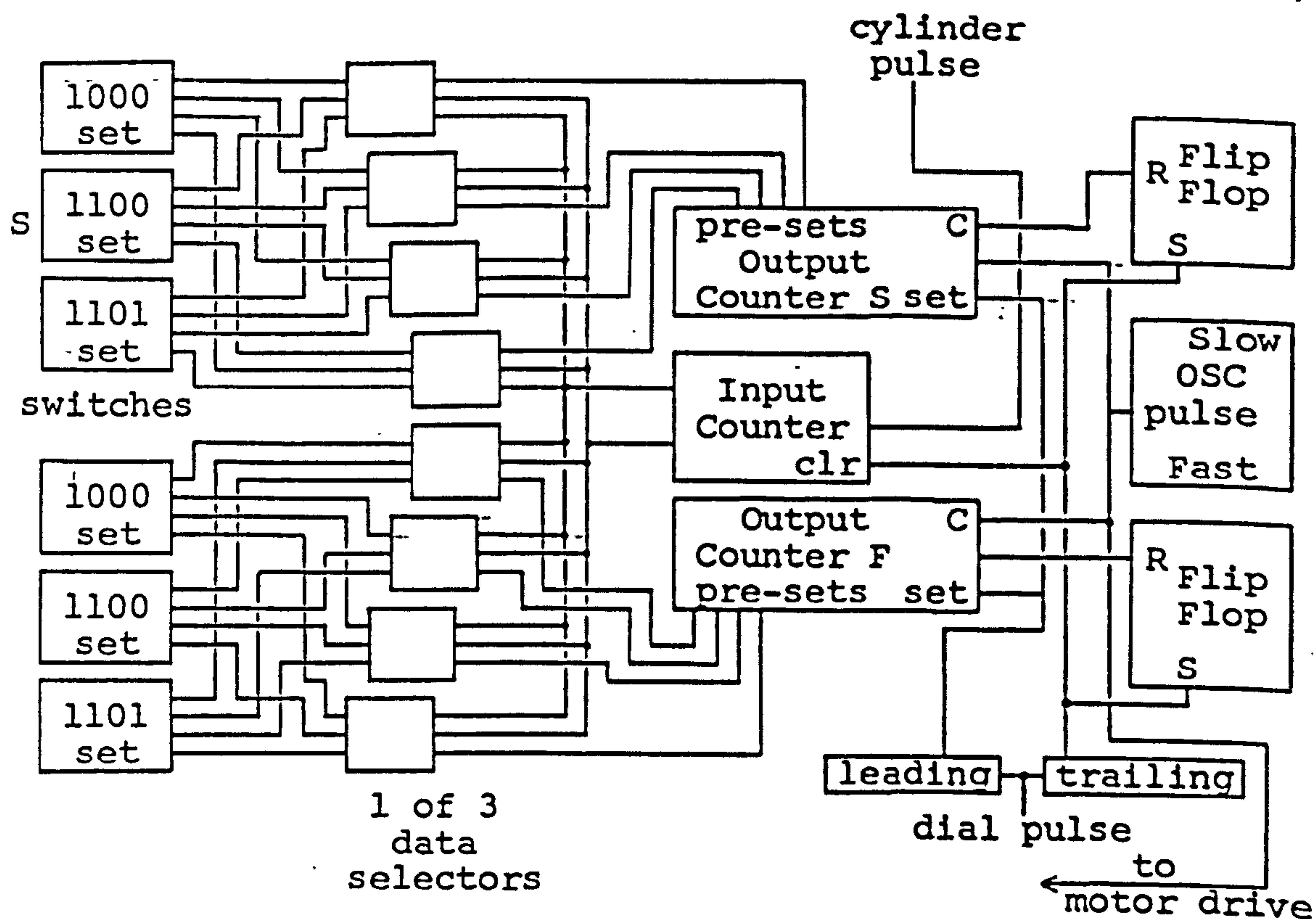


Figure 3.66 Slow and Fast control with switches to control pulse numbers in both conditions.

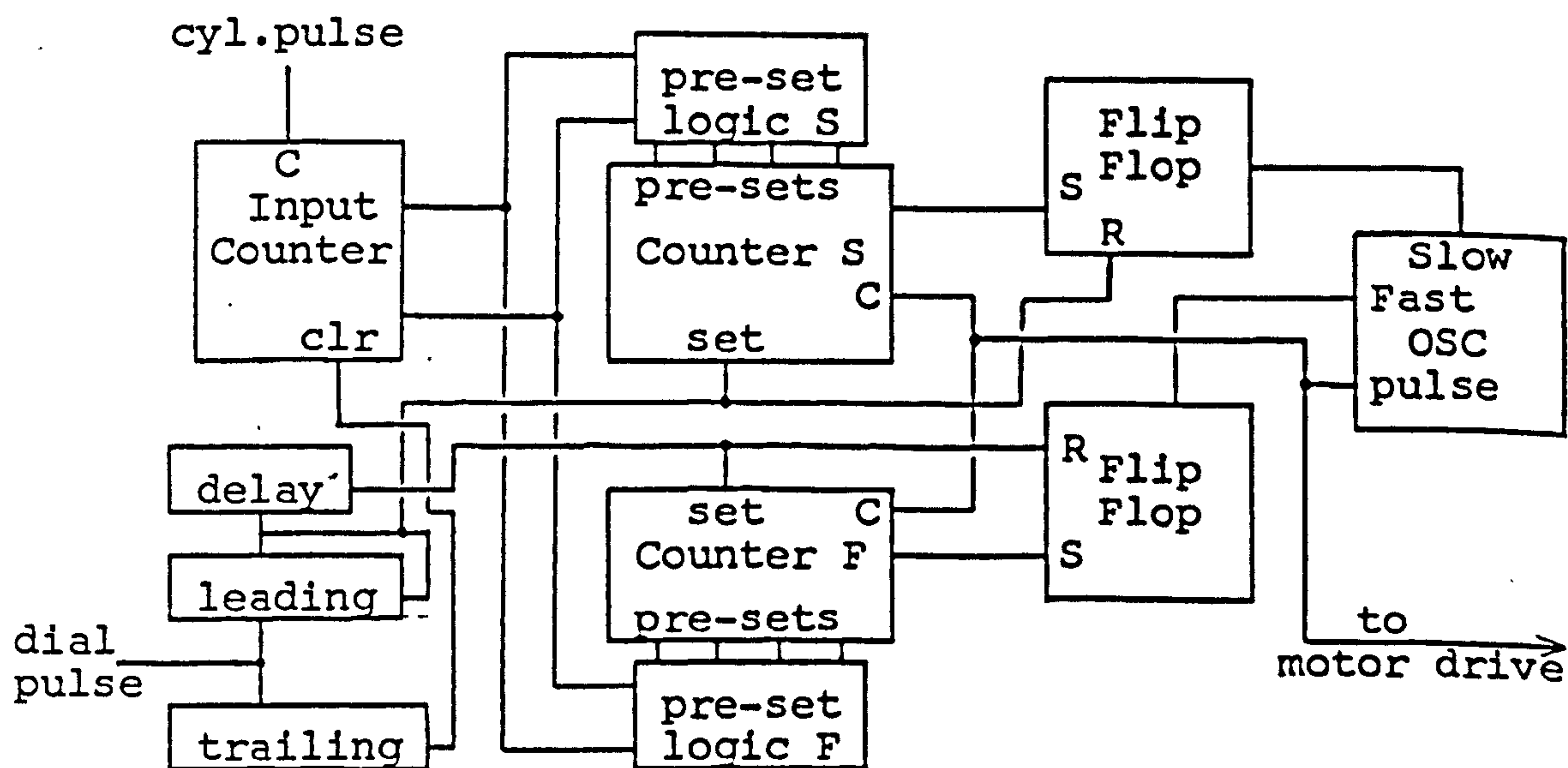


Figure 3.67 Control of Fast and Slow inputs on the oscillator using pre-set logic.

input counter output lines can be easily used to select any number up to 16 to be pre-set.

This system simplifies the control but it is more difficult to alter the number of pulses to be delivered than when using the previous arrangement. Of course here the pre-sets on the counter could be set from external switching, much increasing the versatility of the system.

3.8.2.3 Utilising Slewing of the Motor

If the motor is to be run out of its stop-start range more switching must be introduced to control the slewing of the motor. A system based on that just described (section 3.8.2.2) but using pre-set counters on both Slow and Fast controls of the 555 ramped oscillator is shown in Figure 3.66. Here three 8 bit switches are used to control two 4 bit pre-settable counters which control the number of pulses delivered with and without the Fast control on.

The system allows any number of pulses up to 16 to be delivered with pre-set L_{1000} , L_{1001} and L_{1101} levels. Thus full utilisation of the 20-2215D200-E1.5 motor with the 053/1 24 V unipolar drive over a 6 ms cycle can be achieved.

An alternative system using logic rather than external switching to control the pre-set lines on the counters is shown in Figure 3.67.

Alternatively the buffered ramp control can come from the RCO RCL circuits (section 3.4.4.2). Here much more flexibility is introduced. A single high frequency oscillator can be used under closed loop control to produce the correct number of pulses. These pulses are then prepared through the RCO RCL combination and presented to the motor. Here

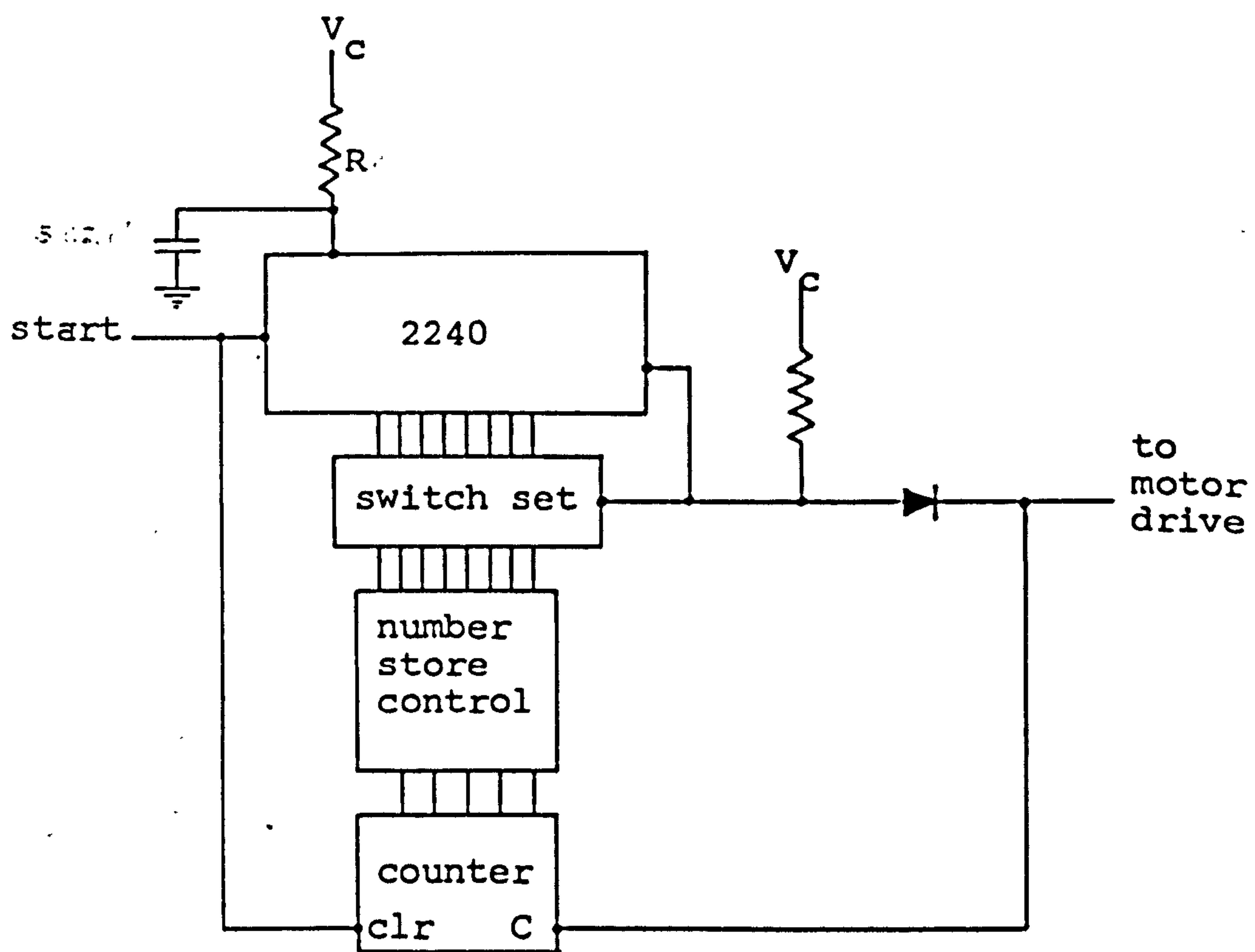


Figure 3.68 The 2240 used to give individual pulse length control.

three sets of RCO RCL will be required so they can be optimally set to produce the ramps for the three different combinations. This system can offer maximum performance from the motor but only by increasing the complexity and cost of the circuit and considerably increasing the setting up time for any change.

3.8.3 Following Actual Yarn Demands

While the systems discussed previously can deliver the required number of pulses to control the length fed in jacquard fabric, they do not follow the demand of yarn from within the system. To do this more precise control of the pulse lengths is needed. This can be achieved by using the 2240 programmable timer to produce the pulse train for the motor. If this is connected as a frequency synthesiser as shown in Figure 3.32 section 3.4.2 the period of a pulse delivery is $T(N+1)$ where N is the number on the binary counter and T is equal to RC which can be set as required. By presenting a series of numbers onto a switch such as the CMOS 4016 each individual pulse length can be controlled. This circuit is shown schematically in Figure 3.68. The required number can be delivered from a series of data selectors or from ROM or RAM memory chips.

For the specific example considered in section 2.2.6.2 for plain knit, as on Table 2.14, eleven steps are required to deliver 4.24 mm in steps of 0.38 mm. To achieve the speeds required the 17-2220D200-E033 motor with the 053/1 24 V unipolar drive must be used. Its performance with a 0.38 mm step will be greater than that presented in section 3.7 Figure 3.57 where a 1 mm step is used. Table 3.4 shows

Table 3.4

Control numbers for the 2240 with a base frequency of 33,000 pulses/s to follow the yarn demand in steps of 0.38 mm for plain. This is within the range of the 17-2220D200-E033 motor driven from the 053/1 24 V unipolar drive.

Step	Step Time (ms)	N
1	0.33	10
2	0.33	10
3	0.33	10
4	0.27	8
5	0.27	8
6	0.36	11
7	0.27	8
8	0.21	6
9	0.27	8
10	0.18	5
11	0.18	5

Table 3.5

Feed control for the jacquard units from the 2240 with a base frequency of 33,000 pulses/s. Modifications from following the predicted demand to keep within the range of the 20-2215D200-E1.5 motor with the 053/1 24 V unipolar drive are shown. A step length of 1.4 mm is used in all cases.

Step	1000		1100			1101		
	step time (ms)	N	step time (ms)	modified step time (ms)	N	step time (ms)	modified step time (ms)	N
1	1.14	37	0.60	0.80	25	0.36	0.45	14
2	1.17	38	0.96		31	0.69		22
3	1.74	57	0.84		27	0.63	0.67	21
4	1.95	64	0.90		29	0.84	0.88	28
5			1.20		39	0.96	1.00	32
6			1.50	1.30	42	1.02	0.80	26
7						0.45	0.50	17
8						1.05	0.70	22

the requirements as step/s rates. The changes are all within the performance of the 17-2220D200-E033 with the 053/1 24 V unipolar drive. If the basic oscillator timing period is set at 0.03 ms (33,000 steps/s) then the N required for each step is as given on Table 3.4. These need only be presented as binary numbers in order onto the switching set under control of the counter which counts the eleven step loop. Only a 4 bit N number is needed. This allows the yarn feed to accurately follow the demand within the knitting zone but only using the high power drive.

If the jacquard units are considered as presented in Table 2.14 section 2.2.6.2, but this time limiting the drive to the 20-2215D200-E1.5 motor with the 053/1 24 V unipolar drive using the lower drive current, the actual requirements have to be slightly modified to keep within the range of the motor. Here the three sets of step arrangements must be stored and the appropriate set chosen to be presented to the oscillator. The control numbers required using the base time of 0.03 ms are shown in Table 3.5. As the numbers range up to 64, a 7 bit number must be stored (compared to the 4 bit in the plain case). With this system it is possible to have good control of the feed to all three jacquard units. In actual practice the four jacquard units must be considered and in the example 1001 is a mirror image of 1100 and so can be achieved by running through the step sequence in reverse.

Here of course the four units must be detected. A serial shift register is proposed as previously presented in section 3.6.3 Figure 3.55. A pulse train must be produced which derives a pulse for each dial needle to control the

shift in. By using the serial in, parallel out register the delay between input and output control can easily be chosen and controlled.

3.9 Conclusions and Possibilities

This chapter has shown that several different systems for driving stepper motors can be used enabling several systems of yarn feed to be set-up. Either a microprocessor or a hardware system can be used to control the motor depending on the versatility of the system required. These systems must now be tested on the knitting machine to see if their bench potential can be utilised in an actual knitting situation.

Chapter 4

Applications of Yarn Movement Control on Knitting Machines

The previous chapter has described several systems which seem to have considerable practical potential for the control of yarn feed. However to examine their real ability it is necessary that they be used on a knitting machine. It is only under these conditions that performance can be fully assessed.

4.1 Length Control per Needle

The first system to be examined uses a stepper motor feed which delivers a controlled length of yarn for each needle that passes the feed point.

4.1.1 Applications on a Circular Machine

The investigation was carried out on the Wildt Mellor Bromley 12 gge teaching machine knitting plain fabric using sinkers. A 2/22s (90 Tex) acrylic yarn and an 8 mm loop length were used to give a fabric with a tightness factor of $12 \sqrt{\text{Tex}}/\text{cm}$. The basic cycle time per needle of the teaching machine is 4 ms in its medium range and 6 ms in its low range. The feed system used the 20-2215D200-E1.5 motor with the 053/1 24 V unipolar drive. A pulse train was derived from the detection of the needles through an optical slot using the circuit described in section 3.8.2. This pulse train was then used to control pulse delivery to the motor. The experimental layout is shown in Figure 4.1.

4.1.1.1 Single Step

For this application the built in oscillator on the 053/1 drive board was not used. The needle pulse was converted into a suitable size pulse which was then used to step the translation sequence on the board through an open collector transistor on pin 9 of the drive board. Thus one step on the motor was delivered for each needle passing the feed point. To obtain the desired loop length (8 mm) a 32 mm radius drive wheel was used, stepped up by a ratio 1:8 from the motor which drives at 200 steps/revolution. This gearing was necessary as the motor produces insufficient torque to directly drive the inertial load of a large wheel. The torque required to drive the yarn is about 0.25 kgcm which should be within the range of this particular drive system. However, care must be taken especially where speeds in excess of 2,000 steps/s are reached. Here only 250 steps/s are required to match the 4 ms cycle time of the knitting machine in its medium range.

Although a wide swing in input tension occurred due to the stepping action of the motor (see section 2.2.6.2) knitting was achieved satisfactorily. No ramping control was used on the motor and it stayed within its stop-start range due to the speeds used. The motor produced sufficient torque to apply only 70 g tension to the yarn and, while this was insufficient to break the yarn, it is far higher than acceptable knitting tensions. By careful relative positioning of the drive pulse (by moving the optical slot) it was possible to observe an optimum tension condition as expected (see section 2.2.6.2).

This experimental arrangement served to show that the

stepper motor yarn feed can be used to knit fabric. It is, however, not particularly useful as any change in drive length requires a change in drive wheel.

4.1.1.2 Multiple Step

Here the needle pulse is used to trigger a burst of four pulses instead of the single pulse used in section 4.1.1.1. The inertial load of the 63 mm radius drive wheel was still too great for the motor so a 1:2 gearing was used with the 32 mm radius drive wheel. The basic pulse train for the four pulses was set to be delivered at 800 steps/s, which is just inside the stop-start range for this arrangement so no ramping of the motor was used. Here the knitting machine could only be run in its low range (6 ms cycle) where 670 steps/s are required, in the 4 ms cycle 1000 steps/s are required which is outside the stop-start range. Once the motor was set running however it was possible to increase the step delivery rate to within 4 ms so with ramping control the medium speed range could be used.

The torque of the motor was now such that the yarn could be controlled up to a tension of 250 g. Also the flexibility of the system was increased in that the number of pulses can be controlled. Here the number of pulses delivered was controlled by means of closed loop control on the oscillator through the Slow control as discussed in section 3.8.1.

4.1.2 Considered Application on Fashioning Machine

This type of system could be of practical use on the full fashioning frame. When the yarn is fed from the side

additional control would be required to alter the delivery for each direction of feeder movement. If the single step per needle is used a means of changing the step length must be included. This could be done by altering the gearing between each direction. As the feed momentarily stops with the direction change this point could possibly be used for the gear change. The effect at the edge of the fabric must also be considered. It must be ensured that the motor steps when the yarn is required in the knitting zone. Here the optical detector would have to be placed on the feeder and so traverse across the machine. Only a small amount of yarn is required at turn around and this will automatically be allowed for from the initial setting up.

If multiple steps are produced for each needle then this step length, as long as it is closely related to the needle spacing, can be used to control the delivery in both directions. If the step length equals twice the needle spacing the difference between the number of steps required in each direction is one. As three needle spaces is a reasonable loop length then two pulses would be needed going away from the feed side and one pulse when moving towards it. This of course means that the loop length cannot easily be changed. A much larger number of pulses would have to be delivered per needle to gain flexibility in this type of system. This would require ramping of the motor and will be considered in section 4.3.

4.2 Flat Bed Feed

Feed control on flat bed machines is at present extremely poor and so in this area a successful system is practically

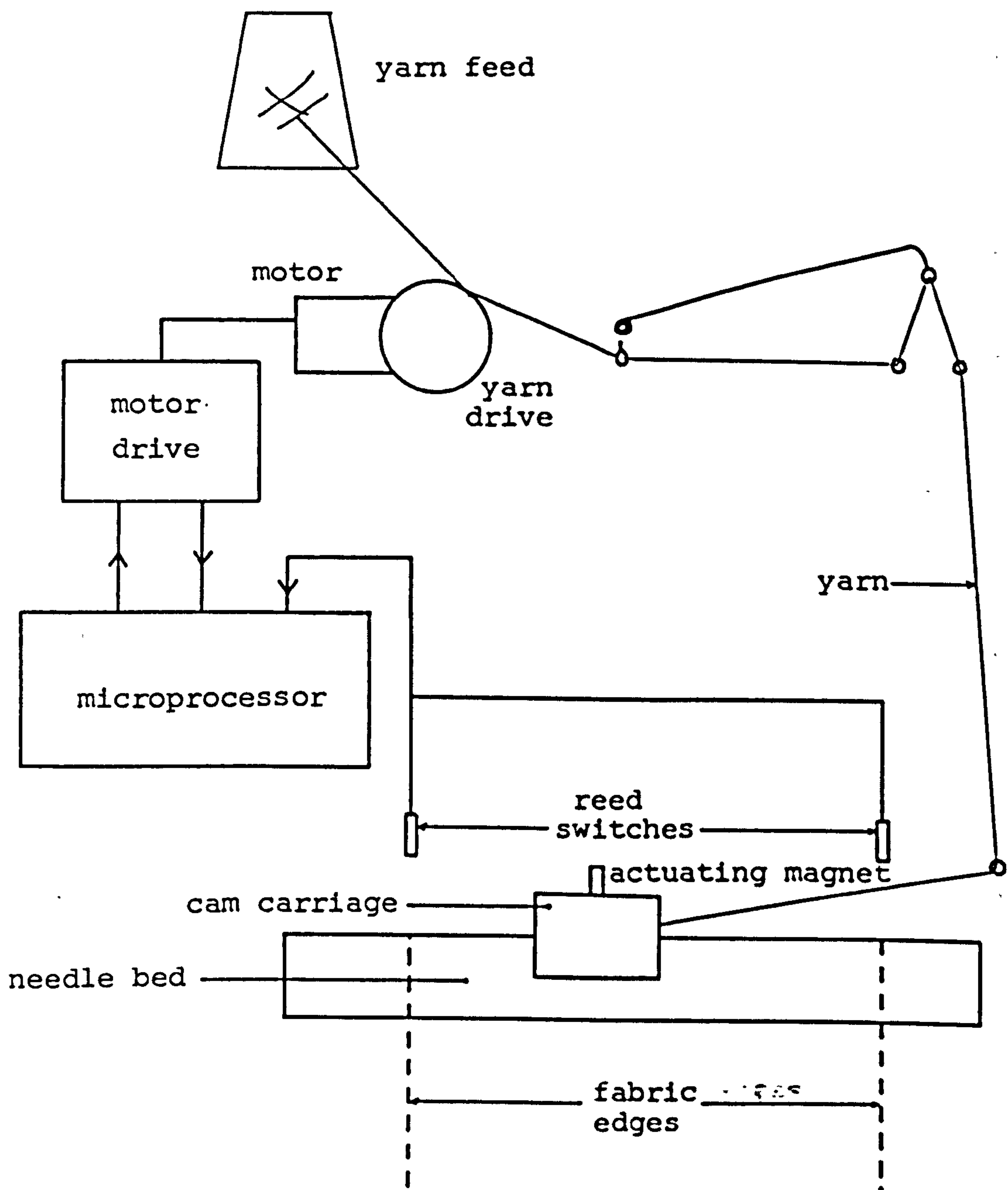


Figure 4.2 Schematic microprocessor controlled feed on flat bed machine layout

important. At present no positive feed system is in commercial use even for control of simple structures.

4.2.1 Microprocessor Controlled Feed

The system described in section 3.6.1 was used with the 20-2220D200-E5.1 motor driven from the LD2 24 V bipolar drive board on a 10 gge Dubied flat bed machine. The layout is shown in Figure 4.2. The speed of delivery is controlled by a combination of Fast and Slow controls on the 555 ramped oscillator. For moving towards the feed side the Slow control only is used and so the speed is set on this section of the oscillator controls. When moving away from the feed side the Fast control is also used and the speed is adjusted by means of this. The motor is controlled through a Basic program (given in Appendix 20) into which the number of pulses to be delivered in each direction is fed. External switching is required to start the cycle and this is provided by reed switches placed on each side of the machine and operated by a magnet mounted on the cam carriage. The program awaits this initiating switch on the input line 0 and then passes the number of pulses to the machine code motor control program, which is given in Appendix 16. When the carriage travels towards the feed side the Slow only flag is set by directly loading into its memory location.

This system was successfully used to produce a range of plain (tubular) and 1x1 rib fabrics. The initial setting up required that the speed of the oscillator on both Slow and Fast controls be matched to the away from feed side speed and the Slow control adjusted for the towards feed speed. Adjustments also had to be made relative to the

knock over depths and the number of pulses. While this may sound awkward the system proved to be fairly flexible since delivery and knitting took place at the same time and so self adjustment depending on actual feed tension occurred by modifying rob back. If the system was first set to over feed then, while knitting single courses, the number and speed of pulse delivery was reduced to that required (adjusting cams as necessary), setting up was reasonably easy.

A 159 mm diameter drive wheel was used directly mounted on the motor shaft. The bipolar drive on the 20-2220D00-E5.1 motor produces high torque at low speeds and could easily cope with this inertial load. The motor was driven at 400 steps/revolution which gave a single step length of 1.2 mm. A needle bed width of 315 mm with a machine speed of 45 traverses/min was used. Thus a typical plain fabric of 6 mm loop length required 892 pulses at 1530 steps/s when moving away from the feed side and 367 pulses at 628 steps/s when moving towards it. Here a range of loop lengths from 5 to 7.5 mm was found possible using 2/22s (90 Tex) acrylic yarn.

The 1x1 rib required higher speed delivery and reached the limit of speed possible with this arrangement. This provides a maximum delivery of 9.1 mm per needle pair. It required 1220 pulses at 2092 steps/s away from the feed side and 717 pulses at 1200 steps/s towards it. Here to increase the flexibility it would be suitable to gear the motor up.

This system was run over a period of two weeks without trouble. Continuous runs of up to 3 hours were included in the trials. After this time the motor was fairly hot (but touchable) which could be detrimental to some yarns due to drying effects. Only 45 watts power were required to drive

the single motor.

Because of the accuracy of this type of feed it was found possible to run the flat machine without the usual tension compensation arm which allows for turn around. This point could lead to a useful rearrangement of the knitting machine layout requiring less manipulation. During this work the movement of the tension control arm was used as an indication of variation of tension with no tension added by its associated cymbals tensioner.

A problem arose when stoppages occurred due to knots etc. The feed system continued delivering yarn to the full course and could only be stopped with the feed at the end of the machine. An investigation in cutting down the size of the control period was used to try and limit the effect of stoppages. A third switch was incorporated in the centre of the machine and the control broken down into four sections. This proved quite successful and did eliminate to some extent stoppage problems.

As an alternative to the system using the single oscillator with Slow and Fast controls a system using two oscillators was examined. The oscillator on the LD2 board was used with a second identical oscillator externally mounted. The external connections were altered so that each oscillator was controlled by the microprocessor for one direction of feeder movement only. This required choice on the Slow and Fast control outputs and also that either pulse could be fed into the CBI line. This proved successful in increasing the controllable range for 1x1 rib up to 16 mm per needle pair. The increased range was made possible by being able to use the motor in its slewing mode when moving

towards the feed side.

By introducing further switching the microprocessor control system could be used on the flat machine to feed to the full course with plain, rib and tuck effects as long as the yarn requirements across the width were the same. A switching system could be used onto a single oscillator instead of using dual oscillators and a number of pre-set speeds could be used.

4.2.2 Hardware Control

The flexibility in number of pulses delivered which is offered by the microprocessor controlled system is far greater than would normally be required. In the trials carried out a pulse delivery of up to 1700 was used and it would seem that this could easily be supplied from a hardware system with a 12 bit counter. This would also avoid the complicated microprocessor programming which becomes necessary when two motors with separate starting times are to be used as on the common double system flat machines.

A system was investigated using the pre-set switching previously presented in section 3.8.1 and shown in Appendix 18. The fabric was divided into small sections of about 20 needles to reduce the stoppage problems. The pulses going in both directions were delivered at the same speed varying only the number of pulses within the section. Over this number of needles it did not prove successful. However by varying the time for which the Fast control was on, knitting was found possible. To fully utilise this approach the pulse delivery rate must also be controlled.

For the hardware an 8 bit counter was used giving a maximum 256 pulses. The fabric was divided into six sections and so selection of up to 1536 pulses for the full needle width was possible. Using the same step length as in section 4.2.1 for the microprocessor controlled system, length repeats of up to 15 mm per needle pair are usable. Two count selection boards were used both controlling Slow and Fast controls on the oscillator of the drive board. Here some cycle speed control was possible without altering the oscillator settings by varying the number of pulses delivered with the Fast and Slow controls on. All switching of the sections was done off reed switches which did not prove very satisfactory. Not a great deal of fabric was produced by this method but it did show that the system could be set up. Ideally a small cycle (say 8 needles) should be used but this severely limits the use of the 20-2220D200-E5.1 motor because of its poor acceleration. To keep the cycles small the higher powered 20-2215D200-E1.5 motor system could be used. This however was not attempted on the flat bed machine.

By deriving pulses from other machine elements such as the carriage drive sprocket, which gives a repeat of approximately 8 needles on one bed, a fairly cheap low powered drive system might be set up to control non-patterned fabric based on the pre-set oscillator control.

This proposed feed system for flat bed machines with only limited needle selection uses the method of pre-settable counters to provide closed loop control on the oscillator and hence the number of steps of yarn delivered as long as the motor's properties are known. The system is based on hardware and so can easily be duplicated for each yarn to

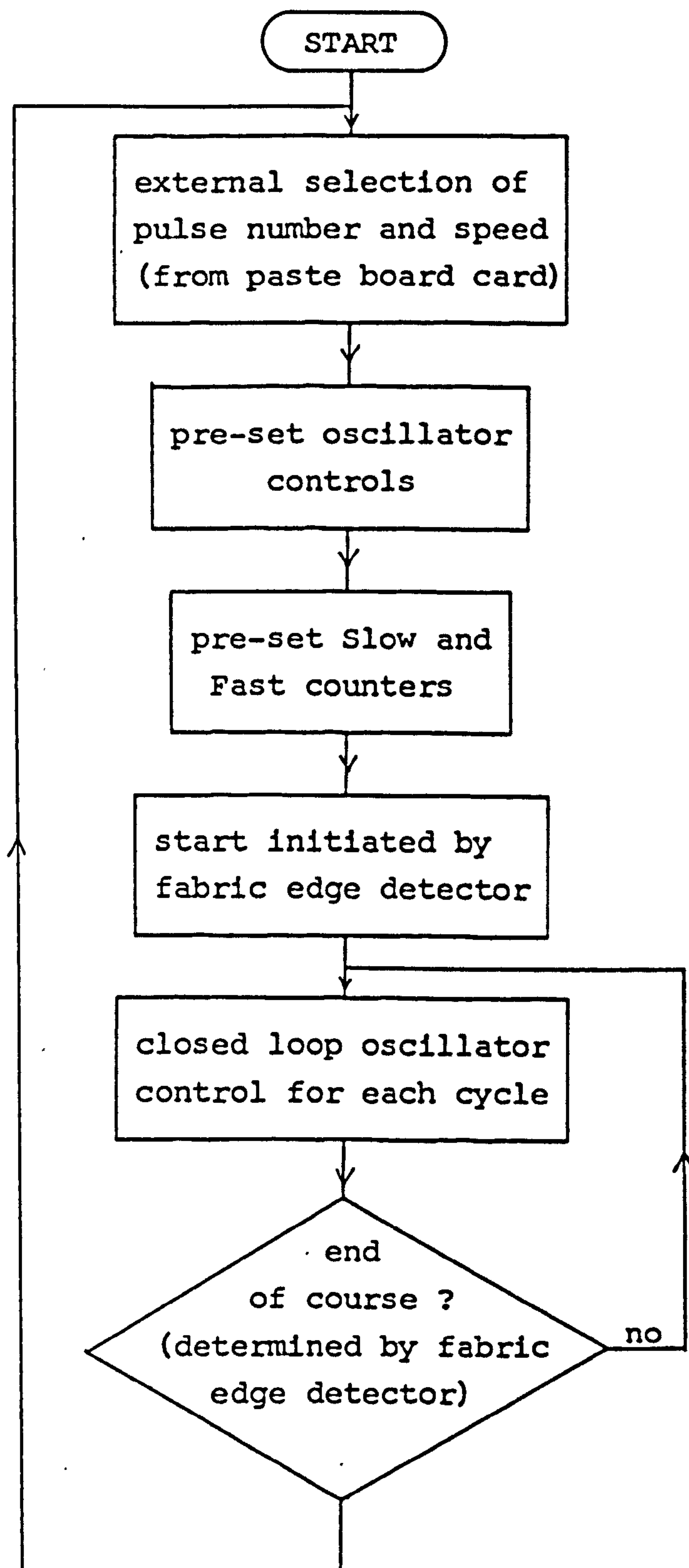


Figure 4.3 Schematic diagram of the proposed flat bed feed system.

to be fed. Each yarn requires a motor, motor drive board and an oscillator control section. When a given yarn is not required the power can be switched out of the motor coils and the motor maintained in a standby condition hence conserving power. On a double system machine only the power to drive two motors is required at any one time. Here to limit power requirements the system can use the 20-2220D200-E5.1 motor with the LD2 24 V bipolar drive but as the same oscillator is used on the 053/1 board the same controls are required as for the other two motor drive combinations.

Here it is proposed that 4 length settings each an 8 bit number be given in each direction along with related speed control. The fabric will be divided into sections of 20 needles by deriving a pulse off the carriage drive sprocket. Detection is also required on the edge of the fabric to indicate when the drive should be initiated. The selections of the four units in each direction can come from the paste board control card or equivalent along with the selection of which motor will drive.

The oscillator control section is divided into six sections as shown in Figure 4.3. The first section takes the selection from the external control (paste board card) and selects from the memory the required length. Here it is proposed that the memory consist of 16 8 bit numbers. This gives Fast and Slow control in each direction for 4 selected lengths each of Fast and Slow being 8 bit numbers. This can best be provided from a ROM chip. The input consists of a 2 bit number selected from the paste board card with a Fast or Slow bit and a direction bit added, to give a 4 bit number which selects any of the 16 oscillator control

numbers.

Once the number is selected it can be used to pre-set in turn both the Fast and Slow control counters as well as the speed on the oscillator for the motor selected. The oscillator speed is controlled by switching pre-selected resistors onto the Slow and Fast speed controls in place of the normal variable resistors.

The pre-set to the counters is provided by an open collector output device using pull-up resistors to the power line. Pre-set on the counters is enabled by the pulse derived from the carriage drive sprocket. This can either drive the oscillator at all times and not present the pulse to the translation section of the drive board until the feeder reaches the edge of the fabric, or only drive when the feeder is over the fabric.

Pulse delivery is initiated when the feeder reaches the edge of the fabric. For each pulse from the drive carriage three timing pulses are required. The first pre-sets the Slow counter and the oscillator speed, the second pre-sets the Fast counter and the third starts the motor drive. This cycle is then repeated again and again until the course is finished. Another detector is used to signal that the course is finished. The control then returns to the conditions for setting from the paste board control card for the next course.

By using the small cycle which is initiated only when the knitting machine is running, problems caused by stoppages are reduced. When the machine is running at slow speed a certain over feeding will occur so some method of taking up the extra yarn must be provided. This can be achieved by the

usual method used for flat bed machines of a tension loaded arm. The drive can easily be mounted behind this device as the motor is small. It must be remembered that the motors will get hot, especially if they remain stationary with current in the coils, and so must be properly guarded.

A proposed circuit for the control of this feed system is given in Appendix 21.

As long as the performance range is kept within that of the 20-2200D200-E5.1 motor with the LD2 24 V bipolar drive the power requirements will only be 90 watts for the two motors running simultaneously. If higher performance is than available from this system is required, especially in the case of shortening the cycle, then the 20-2215D200-E1.5 motor or the 20-2220D200-E033 motor using the 053/1 24 V unipolar drive board will provide higher performance but at 150 or 350 watts respectively for two motors. The low speed torque of the low power system, however, should make it applicable in most situations as long as the cycle time is greater than about 20 ms.

4.3 Jacquard Feed Systems

The development of a flat bed positive feed system is of great importance to the control of consistency between any fabrics knitted on this type of machine. In the case of jacquard fabrics produced either on flat or circular machines to obtain reasonable quality within, as well as between, fabrics a positive feed system is needed. The knitting properties of the units which make up the jacquard fabric are such that without positive feed control the ideal relationship between them cannot be achieved. With negative

feed the quality of the fabric is dependent upon which units are used and how they relate to those around them. The basic problem of inconsistency between $L_{1000} + L_{1101}$ and $2L_{1100}$ (see section 1.3.3), can only be solved by eliminating the 1100 and 1001 units when a positive feed is not available.

4.3.1 Circular Machine

The system described in section 3.8.2.1 with the control circuit given in Appendix 19 was used for a practical trial. This circuit with its dual input/output stage requires cylinder needle detection one unit (distance between knitting dial needles) before the point where the needles start to take on yarn. While on many machines detection at this point was fairly difficult, it could be achieved on the Wildt Mellor Bromley 12 gge teaching machine. For this detection an optical slot was used. Detection of the knitting dial needles, and hence the basic cycle, could be placed before the feeder and so out of the way. The cycle was set to start as the dial needle took on yarn and the machine was run with synchronised timing.

The control was set to provide one pulse for the 1000 unit, two pulses for the 1100 and 1001 units with three pulses for the 1101 unit. These are in line with the ratios achieved on the teaching machine in section 2.5 for repeated units. The motor used was the 20-2215D200-E1.5 driven from the 053/1 24 V unipolar drive board. The built-in 555 based oscillator was used driven only through its Slow control. The knitting machine was run at a repeat cycle time of 12 ms which meant that the speed for a single pulse was 84 steps/s while the fastest speed of three pulses required only 252

steps/s. The oscillator was set to give 400 steps/s so the pulses for the 1001, 1100 and 1101 units were delivered in a burst at the start of each cycle with the 1000 pulse coming just as the dial needle took on yarn. Here a gearing up of 1:8 was used with a 32 mm radius drive wheel to drive the yarn. This gave the same torque requirements as the single step, consideration discussed in section 4.1.1 except the cycle time was twice the size, requiring a slower motor speed.

Under these conditions it was possible to produce positive feed to a two colour jacquard fabric. Lengths fed were verified by removing courses from the fabric. Here it was also possible to run the knitting machine at its medium speed range (8 ms per cycle) successfully controlling the feed. The ratio of 3:1 for $L_{1101} : L_{1000}$ however does not produce an ideal two colour jacquard fabric. Nevertheless L_{1100} was achieved at the required level so the fabric appearance was good.

A similar trial was carried out using a 4:3:2 step relationship for the units. With the same step length as previously the 1000 unit could not be knitted satisfactorily. The drive ratio was reduced to 1:6 which resulted in satisfactory production of some fabric.

The system however offers little flexibility in the drive arrangement and the gearing makes the drive unit rather bulky. Any improvements would require the delivery of more pulses per cycle hence removing the need for gearing and also increasing the choice of ratio between the individual units. Any such increase would require slewing of the motor.

The main problem encountered with this drive system resulted from the positioning of the optical slot to detect the cylinder needles which proved unstable. Detection should be further back from the feed point and the data stored for at least another cycle.

4.3.2 Proposed Development on Circular Machine

Studies described in section 1.3 have indicated that the ideal value of the $L_{1101} : L_{1100} : L_{1000}$ ratios for two colour jacquard are 2.2 : 1.6 : 1 and for 18 gge fabric this could be produced with feed lengths of 11, 8 and 5 mm respectively. This would require approximately the same settings used for Fabric 1 of the three colour jacquards (Appendix 4) with an increase in rob back on the 1100 and 1001 units to just beyond the half restricted rob back condition (see section 2.2.5.2.2). While this fabric was produced as a three colour jacquard, a very similar fabric was produced as a two colour jacquard fabric¹⁴⁴ (see Table 1.4 opposite page 36) but in a slightly tighter version. For three colour fabric however the ideal ratios would seem to be 2.6 : 1.8 : 1 and the corresponding length requirements for an 18 gge machine 13, 9 and 5 mm. These are approximately the L_{1101} and L_{1000} values of Fabric 3 of the three colour jacquard fabrics produced (Appendix 4). Again if the rob back is increased by input tension control the required value lies just beyond the theoretical half restricted rob back case for the 1100 unit.

The suggested feed lengths for both the two and three colour jacquard cases could be achieved using the 17-2220 D200-E033 motor with the 053/1 24 V unipolar drive producing

Table 4.1

Number of steps with speed setting for Slow and Fast controls and pre-set logic required. The pre-set logic pre-sets through an open collector output inverter. Logic before this inverter is shown. Slow speed is 1000 steps/s and Fast speed is 3300 steps/s.

Two Colour Jacquard

Unit		Number of Steps	Counter Settings (steps/s)		Time for Delivery (ms)
			Slow	Fast	
1000		5	5	0	5.0
1100 and 1001		8	8	4	5.6
1101		11	11	8	5.0
Input Count		Inverted Slow Pre-set		Inverted Fast Pre-set	
2^0 2^1		2^0	2^1	2^2	2^3
A B					
0 0		0	1	0	1
1 0		1	1	0	1
0 1		0	0	1	0
logic required		\bar{A}	\bar{B}	\bar{B}	\bar{B}
two inverters only					

Three Colour Jacquard

Unit		Number of Steps	Counter Settings (steps/s)		Time for Delivery (ms)
			Slow	Fast	
1000		5	5	0	5.0
1100 and 1001		9	9	5	5.9
1101		13	13	10	5.7
Input Count		Inverted Slow Pre-set		Inverted Fast Pre-set	
2^0 2^1		2^0 2^1 2^2 2^3		2^0 2^1 2^2 2^3	
A B					
0 0		0 1 0 1		1 1 1 1	
1 0		0 1 1 0		0 1 0 1	
0 1		0 0 1 0		1 0 1 0	
logic required		0 \overline{B} A \overline{A}		\overline{A} \overline{B} \overline{A} \overline{B}	
two inverters		OR			
and one OR		B \overline{B}			

a basic 1 mm step within the 6 ms cycle. The proposal is to use the system with two 4 bit pre-settable counters previously presented in section 3.8.2.2. It is proposed that the detector be mounted in the feeder and an appropriate delay set to await the detected unit reaching the feed zone.

If the machine is run at a 6 ms cycle the oscillator control settings to give the required number of pulses are as shown in Table 4.1 along with the pre-setting logic required. Pre-set logic rather than switching has been used to reduce the amount of circuitry. Alternatively three 8 bit switches could be used with the input count acting to select which switch pre-sets the counters. This would increase the range of fabrics which could be produced.

This system, while offering the flexibility required, is high on power usage. To deliver this degree of selectivity the 17-2220D200-E033 motor with the 053/1 24 V unipolar drive must be used and this requires 175 watts per motor.

For the 20-2215D200-E1.5 motor using 75 watts per feed the maximum pulse delivery at a step length of 1 mm is 9 in 6 ms. Here then for a stepped feed the only achievable lengths to maintain the internal balance will be 9, 7 and 5 mm or 9, 6 and 3 mm for the three units respectively. 9 mm is a shorter L_{1101} than achieved in any of the practical studies and so it is questionable if either of these fabrics could be knitted. If the step length is increased to 1.6 mm then 8 steps can be delivered in the cycle. This enables unit lengths of 12.8, 11.6 and 6.4 mm or 11.2, 8.0 and 4.8 to be used. The latter would be quite reasonable for a two colour jacquard although even the first case would give knittable ratios similar to those achieved

in section 4.3.1. The flexibility of the system however is very restricted.

A reduction in power could warrant this loss in the flexibility obtained using this motor. It would seem that the power problem would limit the use of this type of jacquard drive where many feeders are used.

On a fairly coarse gauge circular machine it may be possible to use the 20-2220D200-E5.1 motor with the LD2 drive board operated in its Slow only range (approximately 600 full steps/s) which would require only 45 watts per feed. However only the 3 : 2 : 1 or 4 : 3 : 2 ratios could be used, neither of which produce the ideal arrangement. This would be possible on a 12 gge machine.

For any machine of finer gauge or where more suitable ratios are required the 20-2215D200-E1.5 motor with the 053/1 24 V unipolar drive would be needed at 75 watts per feed. However the performance of this system just allows it to be used on the 18 gge machine but with no flexibility. For versatile control the 17-2220D200-E033 motor would be needed using 175 watts per feed. If this degree of flexibility is required a more sophisticated current regulated drive (see section 3.2.4) could be used instead of the inefficient resistance limiting drive. This would reduce the power problem but only at a considerable increase in drive unit cost.

4.3.3 Flat Bed

Because only two yarns are fed at one time the flat bed jacquard machine offers a real practical possibility for applying positive feed to jacquard structures. The power

requirement for the most flexible drive system now becomes 350 watts which would not seem excessive.

Here the added complication of direction must be considered in the system. To achieve uniform fabric in both directions a basic step length must be used which is related to the gauge. Suppose an 18 gge machine is required to knit the ideal length ratios 2.2 : 1.6 : 1. The respective unit lengths of 11, 8 and 5 mm might be used. An 18 gge machine has a 1.4 mm needle spacing. Thus the requirements in each direction would be 12.4, 9.4 and 6.4 mm away from the feed side and 9.6, 6.6 and 3.6 mm towards the feed point. This would be difficult to achieve with a given step length without an excessive number of steps, as here a 0.2 mm step length would be the largest that could be used. Hence a different combination would have to be used. If a step length of 0.7 mm or half the needle spacing is used 15, 11 and 7 steps would feed 10.5, 7.7 and 4.9 mm respectively. This would give around the required ratios maintaining the correct relationship between the units. Actual numbers of steps required would then be 13, 9, 5 and 17, 13, 9 for the two directions. This would require rather a lot of steps when moving away from the feed but could be achieved with the high power motor drive combination. It would seem that a half needle space is a desirable step length when using a flat bed machine. For a coarser gauge machine with a correspondingly longer cycle time the step length could be a smaller fraction of the needle spacing still allowing time for delivery of the yarn.

For example a 10 gge machine would allow almost twice the time to deliver the yarn and so a quarter needle space

step of about 0.63 mm could be used. This would of course require a greater number of steps to achieve the desired length of approximately 34 mm for the longest unit moving away from the feed side. Thus it would seem that here the 4 bit pre-settable counters used in the circular case would be difficult to implement while still maintaining a desirable relationship between the units. If the 18 gge case is considered using two less pulses for the 1101 unit and one less pulse for the 1001, the desired relationship between step size and needle space would be maintained but the unit length ratios become 11 : 10 : 7 which is extremely low for the $L_{1101} : L_{1000}$ and would not produce a desirable fabric.

If a step which is equal to the needle spacing is used i.e. 1.4 mm, a relationship in unit lengths of 9.8, 6.0 and 4.2 mm can be achieved with 6, 4 and 2 pulses when moving towards the feed side and 8, 6 and 4 when moving away. This length combination is close for L_{1101} and L_{1000} to that of the $T_1D_0P_1$ value at the low cam setting and the L_{1100} value should be able to be achieved by increasing the rob back (Table 2.8 facing page 66 section 2.2.5.2.2). This limits the pulses to within the range of the 20-2215D200-E1.5 motor with the 053/1 24 V unipolar drive and keeps within the 4 bit range. This would also offer good ratios for the three colour case. The other alternative using the half needle space step with 15, 11 and 7 mm lengths for L_{1101} , L_{1100} and L_{1000} respectively giving the lower $L_{1101} : L_{1000}$ would be more suitable for the two colour case.

Here then either a system with 4 bit or 5 bit pre-settable counters could be used, but the relationship of step size to gauge must be maintained so direction change can be

accommodated. The feed system requires three pre-set step numbers in each direction. Again the optical detection of the needles can be used to select the required unit using the basic cycle time between the knitting dial needles. Six 4 bit numbers can be used as the pre-settables on both the Fast and Slow counters, i.e. one set of three in each direction. Here rather than using ROM as when eight 8 bit pre-settables are required, six 8 bit numbers can be stored on eight 1 of 8 data selectors under the control of a 3 bit selection number. The first two bits of the selection number are again found by counting surface needles while the third bit is dependent on the direction of movement. As this system is triggered off the needles no edge detection is required. A detector for each direction may be required in front of the feed position. However, it may be possible to use only a single detector, if this is mounted directly in the centre of the feeder. It would seem that any detector mounted on the feeder could be easily damaged, especially during feeder change. Thus it may be necessary to detect the selected needles inside the cam box, in which case detectors would be required on all the face side lifting cams. This could be achieved through optical or magnetic means.

While problems of placement of detectors and limitations on step size exist for the flat bed machine, the development in the use of these machines for jacquard fabric production makes this jacquard feed system a practical reality. As only two motors are driven at one time the running costs associated with the power required for the motors do not seem so daunting as in the circular case.

4.4 Take-up Control

While the focus of this work has been to provide the right amount of yarn to the fabric, the actual fabric state and hence the finishing requirements are also important. Once the feed length and machine gauge have been decided the take-up should be set relative to these.

When the stepper motor feed is used the feed control information is present as an electronic signal and this may also be used to control the take-up. The take-up might also be controlled by a motor system. However, as the stepper motor feed in itself is somewhat inflexible to yarn feed length change, this type of linked control becomes somewhat academic. It is important here to ensure that the take-up is set relative to the amount of yarn fed in. Perhaps the best guide to "relaxability" is the ratio C/W . This gives an indication of the relative distribution of the yarn and any distortions occurring in the loop. This ratio on the machine is basically linked to the machine gauge. Ideally feed lengths and take-up conditions should be chosen to maintain this ratio at its best level and so make any finishing operation simple.

For two bed fabrics a basic problem exists due to the cross over lengths between the two beds. In the finished fabric these are mainly within the loops but are formed in between them. Thus some sort of relaxation will always be necessary unless this length distribution can be manipulated on the knitting machine. This would necessitate that a controlled "relaxation" path be followed between the needles and the take-up rollers.

On flat machines the fabric must be allowed to come

in at the edges if any form of relaxation is to take place. This would lead to path length differences between the needles and the take-up rollers across the fabric width and hence undesirable bowing in the fabric. Alternatively some stretching action with the edges held might pull the yarn into the loops. This however would result in a greater load on the needles and so from this aspect is undesirable. Thus it would seem that some external relaxation will always be necessary.

On circular machines more flexibility is possible, though the problem of removing the cross over sections still remains. However the circular machine does offer a more controlled relaxation path. With proper "spreading" control the tube of fabric could be allowed to collapse in from the needles, maintaining the desired relationship for C/W. The flattening of the tube to allow it to be wound onto the take-up rollers also presents a problem. The application of a greater load from the take-up rollers would reduce the cross over lengths by drawing them into the loops but would also distort the relaxation path on the machine. Alternatively reducing the take-up tension to a minimum would increase the relaxation control of the spreader but may make it difficult to reduce the cross over sections.

If the fabric is made with small loops the action of casting off previously formed loops will act to draw more yarn into the loop due to its passing over a needle with a closed latch.

Nevertheless, for any high friction yarn the finishing requirement will cause problems. It is best to limit the space between the needle beds as this, as well as reducing

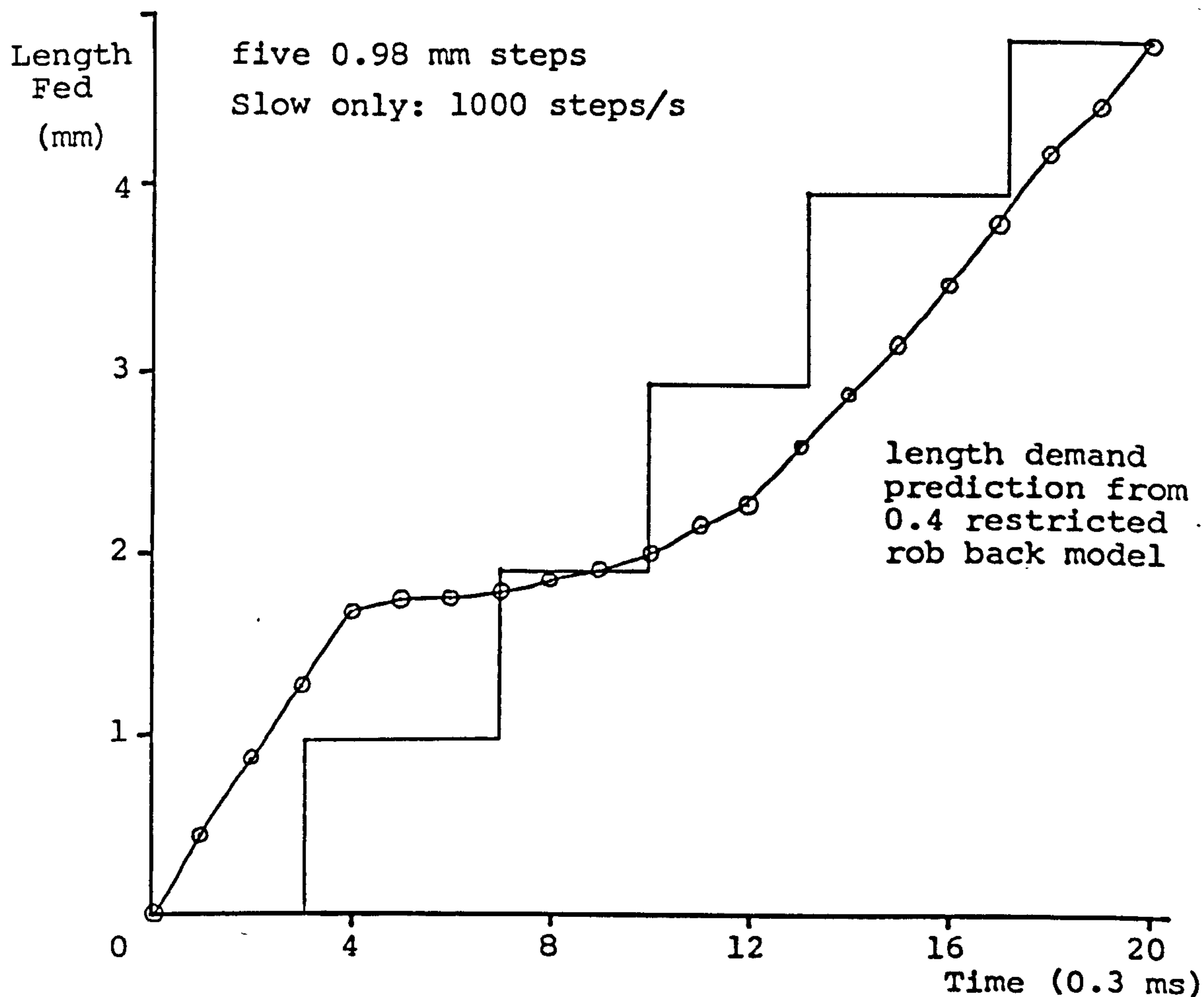


Figure 4.4(a) 1000unit; KOC = 2.3 mm, KOD = 2.0 mm, D = 1.4 mm.

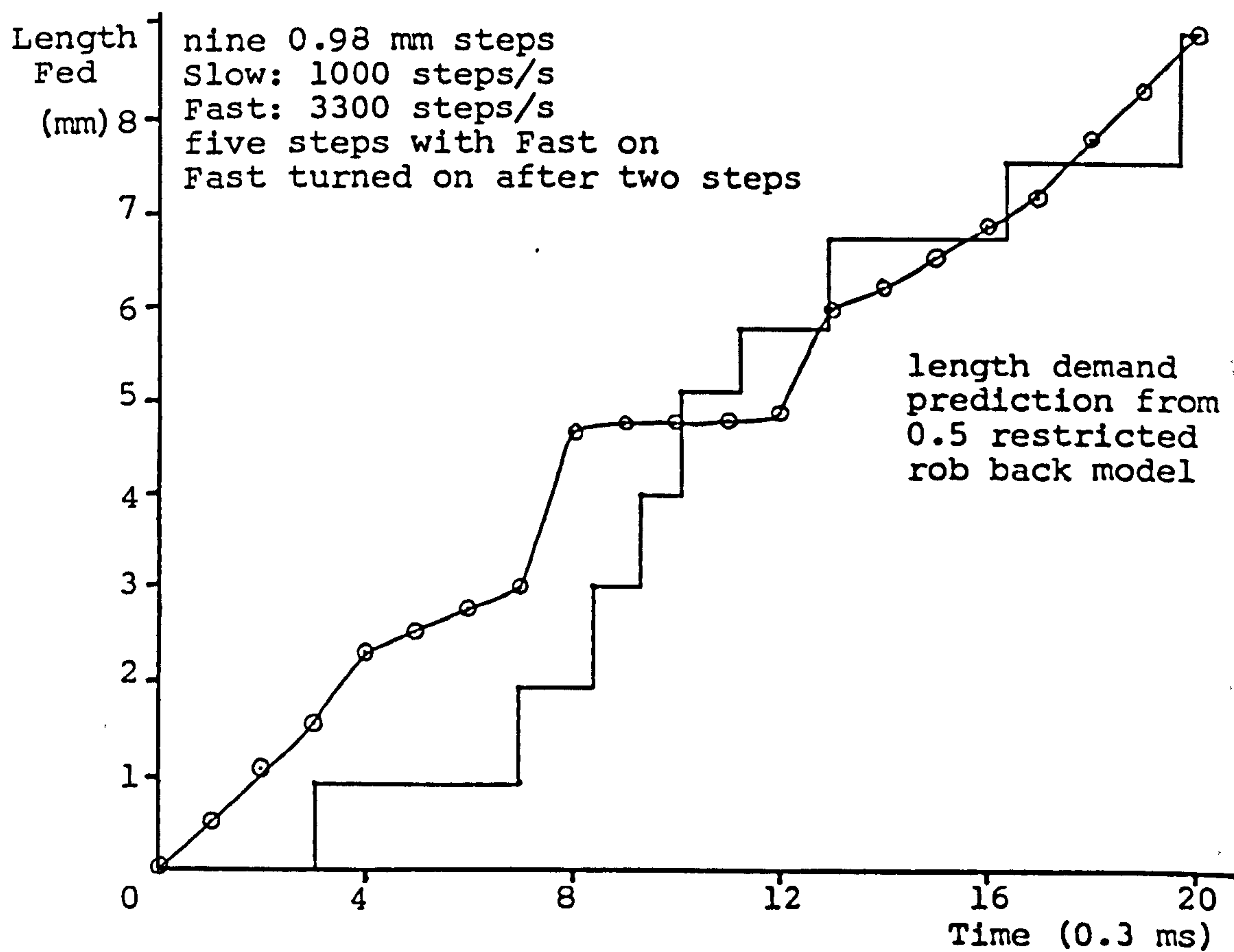


Figure 4.4(b) 1100 unit; KOC = 2.3 mm, KOD = 2.0 mm, D = 1.4 mm.

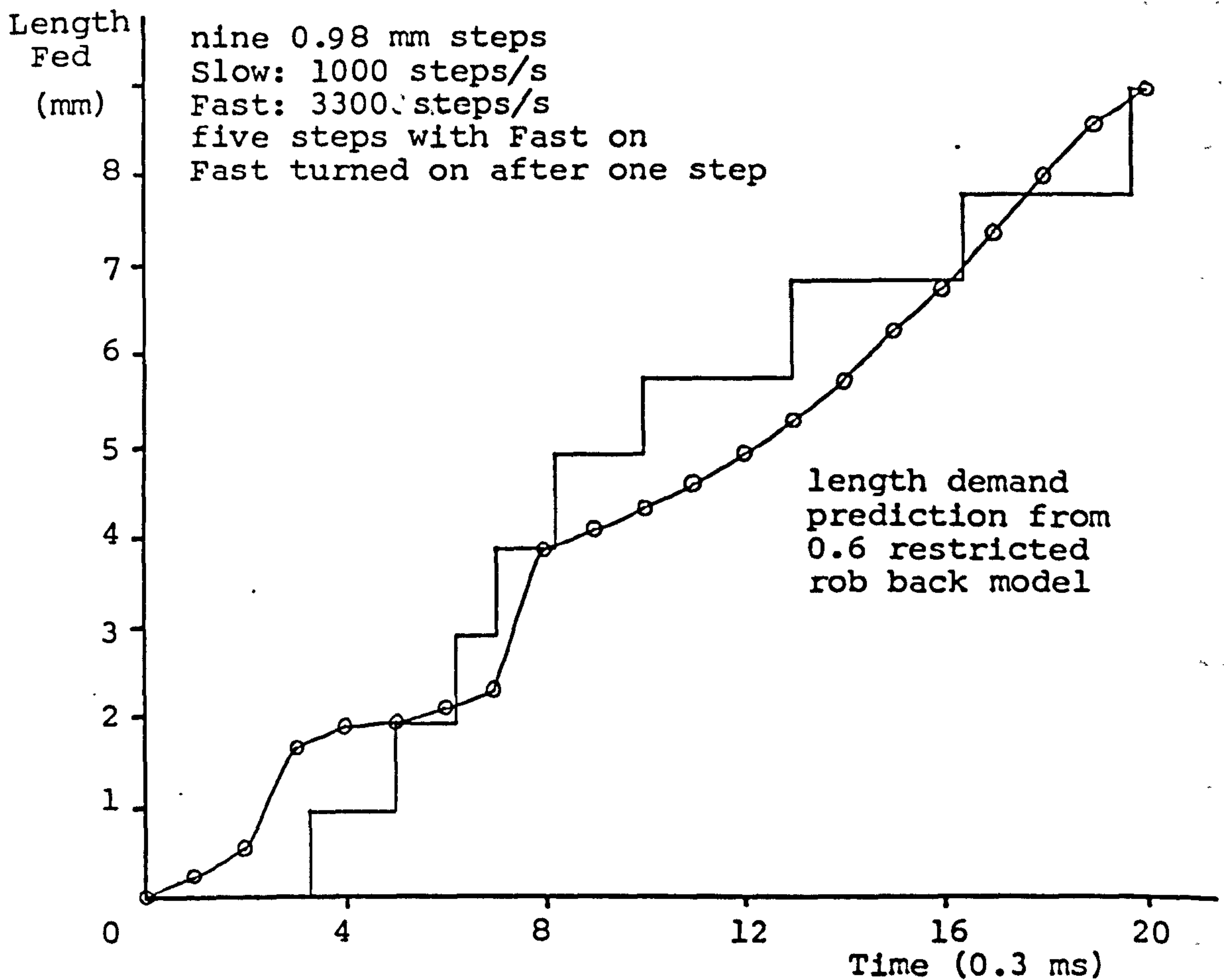


Figure 4.4(c) 1001 unit; KOC = 2.3 mm, KOD = 2.0 mm, D = 1.4 mm.

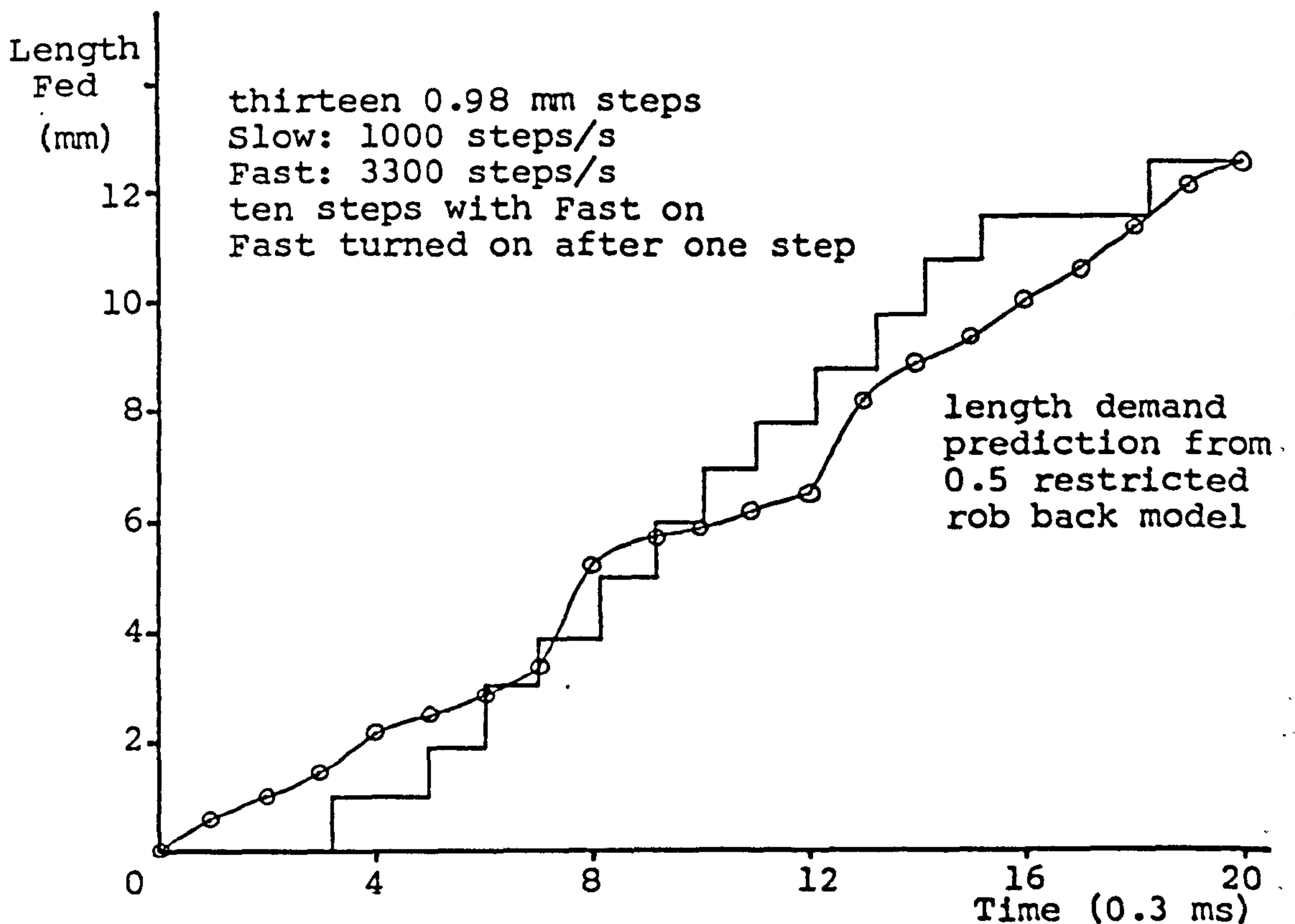


Figure 4.4(d) 1101 unit; KOC = 2.3 mm, KOD = 2.0 mm, D = 1.4 mm.

the cross over lengths, reduces variations in feed rate requirements and makes the desirable "balance" between units in jacquards easier to achieve.

4.5 Matching Actual Yarn Demand

As discussed in section 3.8.3 the high power motor drive combination can fulfil the requirements to match needle movement. No attempts were made, however, to use this system on the knitting machine.

In the jacquard case improvements can be made within the existing proposed system using a ramped 555 oscillator to allow better matching to actual yarn demand. The selections of 1001 and 1100 must be separated as these require different delivery formations. If the cycle is taken between the missing dial needles instead of between the knitting dial needles, the maximum demand for all the units is around the centre of the cycle when the dial needle knits. This requires no alteration in the control section; only a repositioning of the dial pulse input. The yarn drive thus commences as the one needle in the repeat of four which does not knit enters the knitting zone, which will always be a minimum demand point. The 0010 and 0111 units (numbering from the not knitting dial needle) will match quite closely to the accelerated motor. The 0110 unit requires acceleration at the start of the cycle, while the 0011 unit requires it at the end of the cycle. The delivery of this proposed system is shown relative to the theoretical yarn demand in Figure 4.4 (a), (b), (c) and (d). While not ideal, this does not vary greatly from the desired delivery.

4.6 Conclusions to Knitting Considerations

Feed systems using stepper motors were found to be successful on both circular and flat machines. On the circular machine a simple hardware controlled jacquard feed system was successfully run while on the flat bed machine systems controlled from a microprocessor and from hardware were used to knit simple structures. From these trials it was possible to propose systems which would be expected to work for jacquard structures produced on both flat bed and circular machines. The power requirements for each individual feed unit make the flat bed system more likely to be commercially viable than that on the circular machine.

No system to control the take-up in relation to the feed nor system which was sufficiently sensitive to follow actual yarn demands proved a reality.

Chapter 5

Conclusions

Loop length is undoubtedly the single most important knitting variable. It is through control of this that the dimensions and quality of weft knitted fabric can be controlled. While the effect of loop length or unit cell length is quite well known for simple structures, its effect upon patterned fabric is more difficult to ascertain. This work, by using a concept of base cells within the overall fabric, has shown how controlling the length ratios between these cells can maintain consistent quality of the jacquard fabric. However, the three length units which make up these cells cannot be maintained at the correct ratio without using positive feed. A computer program has been presented which, while it is used to develop patterns, lays out the pattern in a form which can easily be organised into the base cells. From this data it is then possible to eliminate the type of cells which cannot be controlled correctly in knitting when positive feed is not available.

The inherent difficulties in feeding yarn into a weft knitting machine have been examined through a model of yarn demand based on the movement of the needles. From this the problems which occur with existing positive and negative feed systems have been highlighted. The model also closely relates to practical studies. A handicap in assessing this theoretical investigation was that the available tension measuring equipment was not sufficiently sensitive to completely examine the rapid fluctuations which occur during knitting. Nevertheless the study has shown how the tension

conditions when knitting the jacquard unit will vary for each unit. The unit which uses the most needles produces the highest tension. This of course compounds when the tension build up within the knitting zone is considered. Here it was also found that positive feed, if developed using a stepped in arrangement, could reduce tension fluctuations through the knitting cycle and also be used to control the correct length into all the cell units for the same machine setting.

Several systems based upon the use of stepper motors for feed control have been developed. The simplest of these are used on flat bed machines where previously no suitable positive feed existed. Using a low power drive (45 watts per unit) the motors can either be controlled from a microprocessor or be driven from specially designed hardware to control the feed to simple structures. Another successful system uses a higher power motor (75 watts) and can deliver its yarn in steps as a needle passes the feed point. This system could have importance if developed for use with shaped garment panels. For jacquard fabrics a system has been developed which can be used to control the yarn feed to the three length groups, again using 75 watts per unit. Here special circuitry has been developed which, from detection of whether a needle knits or not, calculates the length group required and then delivers the required amount of yarn as the unit is knitted. To reduce tension fluctuations an extremely sensitive system has been developed which can follow the actual demand for yarn from the needles as predicted from the yarn movement model. This system however requires 175 watts per motor and so would not seem to be

commercially viable upon the basis of this power requirement.

The first aim; to control the feed to all structures, would seem to have been achieved with the success of both the flat bed and jacquard cases.

The second aim; to present fabric in a known state, is based on the initial control of the loop lengths. From knowing these and using data from previous studies of fabric relaxation it is possible to predict a range of take-up settings for a given gauge machine which allow minimal off machine relaxation procedures. It seems that linking between feed and take-up would be necessary to ensure that fabric is produced within this range. As the feed is now electronically controlled a linking of these systems should not be difficult.

The third aim; to reduce stress on the yarn, has been shown possible by matching the fluctuations in demand at the knitting point with a sensitive feed system. This however could only be done at realistic knitting speeds by using extremely high power which would not seem practical. It is concluded that the storage feed still represents the best unit of feed control for this purpose.

The fourth aim; to reduce machine stresses, has been approached and intimately linked to reducing stress on yarns. By following actual needle movement demands, the stress on knitting elements can be reduced and at present the storage feed again offers the best solution.

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Appendices

	page
1 Tension Variations Off a Cone and Through a Cymbals Tensioner with Speed	i
2 Stress-Strain Behaviour of Knitting Yarns	iii
3 Tension Variations with Speed Through an IRO Storage Feed Unit	vi
4 Three Colour Jacquard Fabrics	vii
5 Pattern Design and Analysis Program	x
6 Computer Implimentation of Yarn Movement Theory and Modifications	xviii
7 Yarn Movement Model Results - Plain	xxxii
8 Yarn Movement Model Results - 1x1 Rib	xxxiv
9 Yarn Movement Model Results - 1000 Unit	xxxv
10 Yarn Movement Model Results - 1100 and 1001 Units	xxxvii
11 Yarn Movement Model Results - 1101 Unit	xxxix
12 Yarn Movement Model Results - Combined Units	xl
13 Yarn Movement Model Results - Flat Bed	xlii
14 Microprocessor Translation and Step Presentation Program	xliii
15 Control of Number and Frequency of Pulses Delivered by Barallel In, Serial Out Facilities on the Microprocessor	xliv
16 Single Motor Microprocessor Control	xlvi
17 Dual Motor Microprocessor Control	li
18 Hardware Duplication of Microprocessor Control System	lvi
19 Toggling Circuit	lix
20 Flat Bed Microprocessor Controlled Feed	lxi
21 Proposed Flat Bed Feed Control Circuit	lxiii

Appendix 1

Tension Variations Off a Cone and Through a Cymbals

Tensioner with Speed

The experiments were carried out using the Rothschild tension measurement system with the Rothschild F-meter take-up device to regulate speed. The results were directly fed into a Solatron microprocessor voltmeter for logging and analysis.

Tension Condition	Speed (m/min)	Tension (g)	Std. dev.	C.V. (%)
guide only	50	3.59	0.35	9.7
	100	4.30	0.43	10.0
	150	4.78	0.52	10.9
	200	5.07	0.63	12.4
	250	5.55	0.75	15.5
	300	6.08	0.94	15.5
cymbals 1	50	4.86	0.48	9.9
	100	5.41	0.58	10.7
	150	6.08	0.59	9.7
	200	6.54	0.68	10.4
	250	7.00	0.76	10.9
	300	7.58	0.98	12.9
cymbals 2	50	7.45	0.64	8.5
	100	8.27	0.75	9.1
	150	9.18	0.66	7.2
	200	9.84	0.72	7.3
	250	10.31	0.76	7.4
	300	10.88	0.87	8.0

Tension Condition	Speed (m/min)	Tension (g)	Std. dev.	C.V. (%)
cymbals 3	50	10.36	0.53	5.1
	100	11.21	0.56	5.0
	150	11.78	0.56	4.8
	200	12.46	0.66	5.3
	250	13.04	0.71	5.4
	300	13.21	0.78	5.9

The yarn used for these tests was a 150 den (16.6 dtex)
textured polyester.

Appendix 2

Stress-Strain Behaviour of Knitting Yarns

Three types of yarn were chosen to examine the stress-strain relationship: 1/30s and 2/24s acrylic and 150 denier textured polyester. The continuous filament polyester and the worsted spun 1/30s acrylic are yarns which are typically used on 18 gge machines, while the 2/24s acrylic is used on 12 gge machines.

Several samples of the acrylic yarns of these types were tested on the Uster Automatic Yarn Strength Tester. The polyester samples were tested under equivalent conditions on the Instron tensile tester.

Results for load and extension at break are given below.

Yarn	Load at Break (g)	Extension at Break (%)
150 den textured polyester	520	32
1/30s acrylic	320	22
2/24 acrylic	620	26

More important than the strength in the knitting situation is the actual stress-strain curve. This was tested on the Instron tensile tester at a 25 cm gauge length with a crosshead speed of 20 cm/min. A 3 g pre-tension was applied.

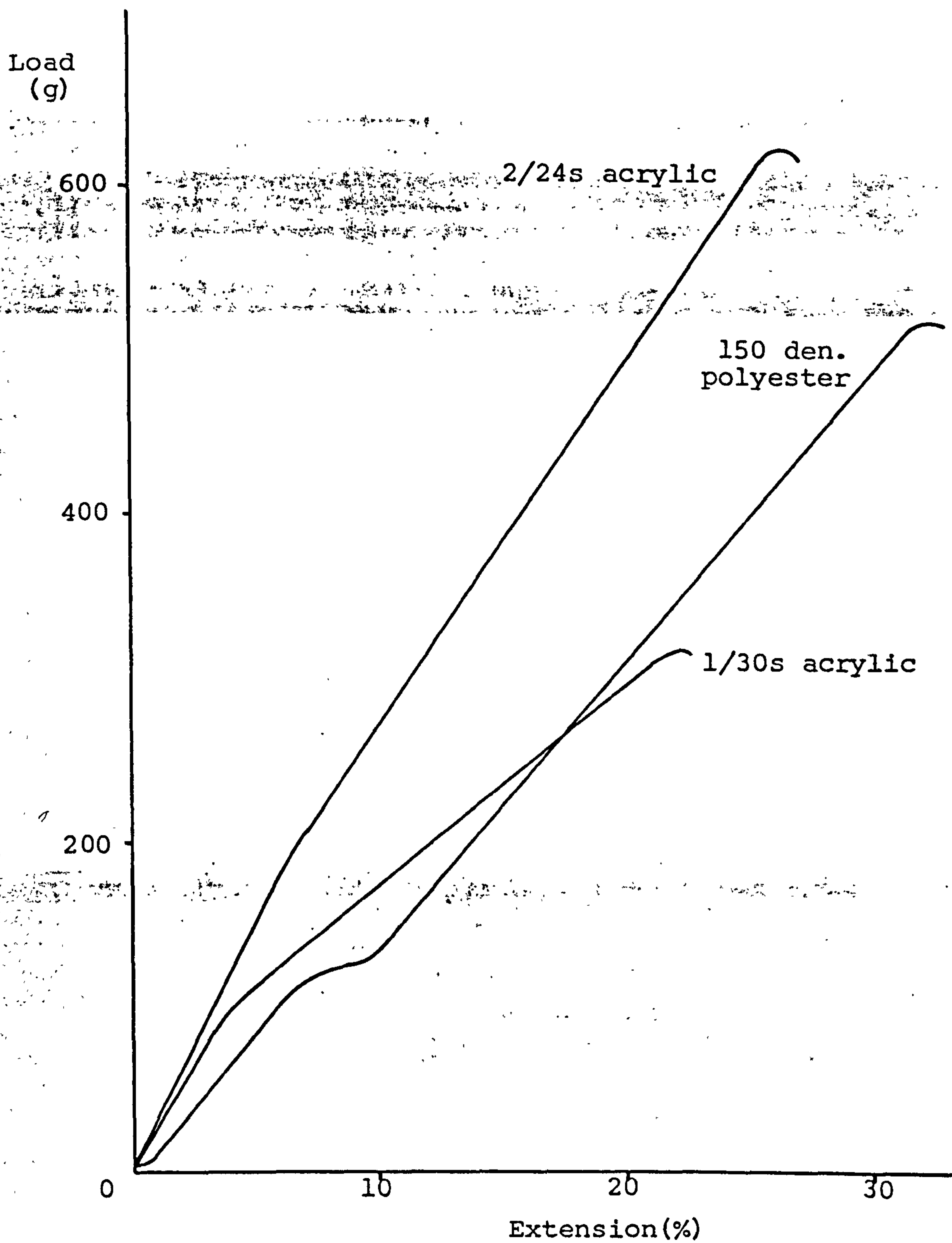
It is important to note that all the yarns have a linear region and then a marked transition before another linear region. For the polyester the linear regions have a

similar slope in both sections and here a higher tension is required to remove the crimp (approximately 5 g). The acrylic samples however show a different slope for their two linear regions. It is the slope of the initial linear region which is most important in knitting and the following results from this region are used for calculations in the text.

Yarn	Transition point		Approx. slope (g/%)
	Load (g)	Ext. (%)	
150 den textured polyester	130	7	18
1/30s acrylic	100	4	25
2/24 acrylic	180	6	30

On the following page typical stress-strain curves are shown for the three yarn types.

Typical Stress-Strain Relationships for
Several Knitting Yarns



Appendix 3

Tension Variations with Speed Through an IRO Storage Feed Unit

These experiments were carried out using the Rothschild tension measurement system with the Rothschild F-meter take-up device to regulate speed. Results were directly fed into a Solatron microprocessor voltmeter for logging and analysis.

Yarn	Speed (m/min)	Tension (g)	C.V. (%)	Std, dev (g)
2/22s acrylic	50	6.91	7.2	0.5
	100	7.03	5.7	0.4
	150	7.04	5.7	0.4
1/30s cotton	50	2.05	6.8	0.1
	100	2.00	6.5	0.1
	150	1.96	5.6	0.1
	200	1.99	5.6	0.1
150 den textured polyester	50	3.10	6.9	0.2
	100	3.00	6.2	0.2
	150	3.05	6.3	0.2
	200	3.03	6.4	0.2

Appendix 4

Three Colour Jacquard Fabrics

A series of three colour jacquard fabrics was produced on the Mayer and Cie OVJA/36 knitting machine. This is a pattern drum machine offering a pattern area of 144x24 for a three colour jacquard. The basic pattern used is a feeder layout only and is shown on Figure 1.12 facing page 37. Negative feed was used at a tension of 5g with 150 den. (16 Tex) textured polyester yarn.

All course lengths were measured over a 240 needle repeat on a HATRA Course Length Tester. The results are quoted per basic unit repeat. At a single feed (feed 1) fifty courses were withdrawn and a mean length of 12.52 mm with a C.V. of 1.2% found. Thus a single feeder knits consistently. On the pattern drums three different positions of the pattern were used, each taken four times. The courses to be measured were withdrawn from the centre two of these repeats. Thus feed 1 knits at position 1 for four revolutions, then at position 13 for four revolutions, then at position 25 for four revolutions and then returns to position 1. Under these conditions fifty courses of feed 1 gave a mean value of 12.47 mm with a C.V. of 2.5%. The increase in C.V. is due to variations between the three feeders used.

In all cases twelve samples were measured taken from the centre two of the four units before rotation of the feeds. The values shown are the means of these twelve samples in all cases. The feeds are always given as shown on the original pattern. L_{1000} had the greatest variation (C.V. 6-8%) of the length groups; much greater than the 2.5%. Both L_{1100} and L_{1101} showed variations of about 3% only slightly

greater than that found from the single unit.

Mean Values for Repeated Units

Fabric	L ₁₁₀₁	C.V.	L ₁₁₀₀	C.V.	L ₁₀₀₀	C.V.
	(mm)	%	(mm)	%	(mm)	%
1	11.86	4.2	9.70	3.0	5.07	6.3
2	12.88	2.2	9.95	4.3	5.06	7.3
3	13.47	4.5	10.58	3.2	5.00	8.1
4	14.36	3.8	10.97	3.5	5.04	6.9

Length of Feed Units for Three Colour Jacquard Fabrics.

		Fabric				
			1	2	3	4
Feed	Unit	KO _c	2.0	2.3	2.5	2.7
		KO _d	2.3	2.3	2.3	2.3
1	1101		12.47	13.26	14.26	15.11
2	1000		4.94	4.90	4.86	5.07
3	1000		4.75	4.70	4.50	4.45
4	1000		5.32	5.43	5.32	4.98
5	1000		5.13	5.11	5.05	5.14
6	1101		11.93	12.76	13.75	14.07
7	1000		4.85	4.82	4.78	4.78
8	1101		11.03	11.39	12.05	13.83
9	1000		5.41	5.38	5.41	5.56
10	1000		5.34	5.22	5.16	4.97
11	1001		9.54	9.88	10.42	10.64
12	1001		9.96	10.40	11.04	11.19
13	1000		4.51	4.54	4.53	4.56
14	1000		5.39	5.42	5.24	5.11
15	1101		12.01	12.62	13.82	14.45
16	1001		9.51	9.92	10.39	10.57
17	1000		5.14	5.11	5.10	4.94
18	1100		9.08	8.83	10.11	10.94
19	1001		9.83	9.68	10.17	10.64
20	1000		5.18	5.22	5.20	5.22
21	1100		9.57	10.10	10.84	11.47
22	1100		9.66	10.00	10.53	10.58
23	1100		10.03	10.33	10.96	11.97
24	1000		5.89	5.87	5.73	5.39
25	1000		4.26	4.23	4.17	5.24
26	1100		9.85	10.28	11.05	11.77
27	1100		10.02	10.44	10.38	11.61
28	10011100		9.45	8.92	9.26	10.63
29	10011100		8.54	8.90	9.24	9.54
30	1000		4.96	5.00	5.06	4.87
31	Group		8.90	8.41	9.78	10.23
32	Group		8.92	9.41	9.92	10.09
33	1000		5.07	4.49	4.63	4.77
34	Group		9.69	10.21	10.84	11.15
35	1000		5.43	5.54	5.43	5.64
36	Group		9.85	10.30	10.88	11.20

Appendix 5

Pattern Design and Analysis Program

This is a program to produce a three colour jacquard design on the screen of a Commodore PET microprocessor and to be able to analyse this pattern into length groups.

Program Layout

Commencing

line number	Function
10	Prepare Space Information for the pattern is stored in an array for which space has to be allocated.
100	Screen Instructions Instructions are placed on the screen to show how pattern can be entered.
400	Machine Information From information of the number of feeders on the knitting machine limits are imposed to be able to produce a pattern of width W and height H (W and H are entered from the keyboard)
1010	Place Design on Screen An area 16x16 of the pattern is displayed on the screen from a specified bottom left hand corner point (X,Y).
1200	Position The position which is at present under consideration is displayed in the top right hand corner of the screen.

- 1400 Alter Design
- By using the number pad, the position on the pattern is altered and the three characters ■, 0 and . can be entered in any position by the letters "F", "G" and "H" respectively.
- 1600 Branch
- By entering "E" or moving off the pattern area displayed a choice of a new pattern, a different pattern section or an analysis of the pattern is offered.
- 3050 Analysis
- From input colour layout with feeders the pattern is broken down into the four jacquard units.
- 4500 Save
- The pattern is stored on cassette tape.
- 5000 Load
- The pattern is entered from cassette tape.

Major Variables

- | | |
|--------|--|
| A(J,M) | Element J,M of pattern array with its value giving the pattern colour. |
| W,H | Pattern repeat width and height respectively. |
| X,Y | Bottom left point of screen display. |
| A2 | Colour analysed. |
| L(0,0) | Number of 1101 units in repeat. |
| L(0,1) | Number of 1100 units in repeat. |
| L(0,2) | Number of 1001 units in repeat. |
| L(0,3) | Number of 1000 units in repeat. |

A listing of the program in Basic follows.

```

10 REM DES+ANALONON
50 PRINT "☐"
60 DIMA(36,36)
70 DIM(2,3)
100 REM SCREEN INSTRUCTIONS
120 PRINT "MAX DESIGN AREA 48*48"
123 PRINT "BOTTOM CORNER SPECIFIED"
140 PRINT "LOCATION SHOWN AT TOP RIGHT"
150 PRINT "CONTROLS          4-MOVES LEFT"
160 PRINT "                  6-MOVES RIGHT"
170 PRINT "                  8-MOVES UP"
180 PRINT "                  2-MOVES DOWN"
190 PRINT
200 PRINT "                  F-ENTERS ■  "
210 PRINT "                  G-ENTERS O  "
220 PRINT "                  H-ENTERS .  "
230 PRINT
240 PRINT "                  L-ENABLES LOAD"
250 PRINT "                  S-ENABLES SAVE"
260 PRINT
270 PRINT "MOVING OFF BOTTOM OR LEFT OF "
280 PRINT " SCREEN ENABLES ALTERNATIVE VIEW "
300 Z$=""
310 PRINT "PRESS ANY KEY TO START"
320 GET Z$:IF Z$=""GOTO 320 : IF Z$ = "L" GOTO 5000
350 REM SHOW DESIGN
400 PRINT "☐"
500 INPUT "NO OF FEEDS";N1
510 IF INT(N1/6)<>N1/6 GOTO 500
1002 PRINT "ENTER PATTERN W , H"
1003 INPUT W,H
1005 IF INT(N/H)<>N/H GOTO 1002
1006 IF INT(24/W)<>24/W GOTO 1002
1010 PRINT "ENTER BOTTOM LEFT POINT "
1020 INPUT X,Y
1030 PRINT "☐"
1040 FOR J=Y TO 12+Y : IF J>48GOTO 1600
1050 FOR M=X TO 12+X : IF M>48 GOTO 1600
1060 IF A(J,M)=0 THEN A(J,M)=46

```



```

1065 A(J+W,M)=A(J,M)
1067 A(J,M+H)=A(J,M)
1070 P=33728-40*(J-Y)+(M-X)
1080 POKE P,A(J,M)
1085 NEXT M
1090 NEXT J
1095 J=Y : M=X
1200 REM POSITION
1201 POKE 33728 - 40*23+36,32
1203 E=J+48
1205 D=D+48
1207 IF D<58 THEN POKE 33728-40*24+35,32
1208 IF E<58 THEN POKE 33728-40*24+38,32
1210 IF D>57 AND D<68 THEN GOTO 1232
1215 IF E>57 AND E<68 THEN GOTO 1235
1217 IF D>67 AND D<78 THEN GOTO 1240
1219 IF E>67 AND E<78 THEN GOTO 1245
1220 IF D>77 AND D<88 THEN GOTO 1250
1222 IF E>77 AND E<88 THEN GOTO 1255
1224 IF D>87 AND D<98 THEN GOTO 1260
1225 IF E>87 AND E<98 THEN GOTO 1265
1226 IF D>97 AND D<108 THEN GOTO 1270
1227 IF E>97 AND E<108 THEN GOTO 1275
1228 IF D>107 AND D<118 THEN GOTO 1280
1229 IF E>107 AND E<118 THEN GOTO 1285
1230 GOTO 1300
1232 POKE 33728 -40*24+35,49
1233 D=D-10
1234 GOTO 1208
1235 POKE 33728-40*24+38,49
1237 E=E-10
1239 GOTO 1210
1240 D=D-20
1242 POKE 33728-40*24+35,50
1244 GOTO 1215
1245 E=E-20
1247 POKE 33728-40*24+38,50
1249 GOTO 1217
1250 D=D-30

```

```

1252 POKE 33728-40*24+35,51
1254 GOTO 1219
1255 E=E-30
1257 POKE 33728-40*24+38,51
1259 GOTO 1220
1260 D=D-40
1262 POKE 33728-40*24+35,52
1264 GOTO 1222
1265 E=E-40
1267 POKE 33728-40*24+38,52
1269 GOTO 1224
1270 D=D-50
1272 POKE 33728-40*24+35,53
1274 GOTO 1225
1275 E=E-50
1277 POKE 33728-40*24+38,53
1279 GOTO 1226
1280 D=D-60
1282 POKE 33728-40*24+35,54
1284 GOTO 1227
1285 E=E-60
1287 POKE 33728-40*24+38,54
1289 GOTO 1228
1300 POKE 33728-40*24+36,D
1305 POKE 33728-40*24+39,E
1400 REM DESIGN LAYOUT
1410 Z$=""
1420 GET Z$: IF Z$="" GOTO 1420
1430 IF Z$="6" THEN M=M+1
1440 IF Z$="4" THEN M=M-1
1450 IF Z$="8" THEN J=J+1
1460 IF Z$="2" THEN J=J-1
1470 POKE 33728-40*23+36,49
1480 IF J<K GOTO 1600
1490 IF J<36 GOTO 1600
1500 IF M<X GOTO 1600
1510 IF M<36 GOTO 1600
1520 IF Z$="F" THEN A(J,M)=46
1530 IF Z$="G" THEN A(J,M)=15

```

```

1540 IF Z$="H" THEN A(J,M)=81
1550 IF Z$="E" THEN GOTO 1600
1560 IF Z$="A" THEN GOTO 3000
1565 IF Z$="S" THEN GOTO 2000
1575 FOR N=0 TO INT(12/W)
1577 FOR O=0 TO INT(12/H)
1579 A(J+N*W,M+O*H)=A(J,M)
1580 POKE(33728-40*(J+N*W)+M+H-X),A(J+N*W,M+O*H)
1585 NEXT O
1589 NEXT N
1590 GOTO 1200
1600 REM BRANCH ROUTINE
1605 PRINT "☐"
1610 Z$=""
1620 PRINT "NEW PATTERN---N"
1630 PRINT "ALTER PATTERN---Q", "SAVE---S"
1640 PRINT "ANALYSE---A"
1700 GET Z$: IF Z$="" GOTO 1700
1705 IF Z$="N" GOTO 100
1715 IF Z$="Q" GOTO 1010
1725 IF Z$="A" GOTO 3000
1800 IF Z$="S" GOTO 4500
2000 END
2010 OPEN 1,4
2020 PRINT#1;"3-COLOUR JAQ"
2030 PRINT#1;"NO OF FEEDS=" N
3000 REM ANALYSE
3001 PRINT"☐"
3005 Z$=""
3010 PRINT "ANALYSE?"
3020 GET Z$: IF Z$="" GOTO 3020
3030 IF Z$="N" GOTO 1600
3050 PRINT "KNITTING ORDER . O Q "
3060 INPUT K1,K2,K3
3070 A1=1
3075 IF A1=1 THEN A2=46
3076 IF A1=2 THEN K=K1
3080 IF A1=2 THEN A2=15
3082 IF A1=2 THEN K=K2

```



```

3085 IF A1=3 THEN A2=81
3087 IF A1=3 THEN K=K3
3090 PRINT "COLOUR" A2
3092 PRINT "CO KK KM MK MM"
3105 FOR J=0 TO (N1/3-1)
3107 L(0,0)=0:L(0,1)=0:L(0,2)=0:L(0,3)=0
3110 FOR M=0 TO (W-1)
3116 IF K/2=INT(K/2) GOTO 3200
3117 REM K ODD
3120 IF M/2=INT(M/2) GOTO 3500
3125 IF A(J,M)<>A2 GOTO 3150
3130 IF A(J,M+1)=A2 THEN L(0,0)=L(0,0)+1
3135 IF A(J,M+1)<>A2 THEN L(0,1)=L(0,1)+1
3140 GOTO 3500
3150 IF A(J,M+1)<>A2 THEN L(0,3)=L(0,3)+1
3165 IF A(J,M+1)=A2 THEN L(0,2)=L(0,2)+1
3175 GOTO 3500
3200 REM K EVEN
3210 IF M/2<>INT(M/2) GOTO 3500
3225 IF A(J,M)<>A2 GOTO 3250
3230 IF A(J,M+1)=A2 THEN L(0,0)=L(0,0)+1
3235 IF A(J,M+1)<>A2 THEN L(0,1)=L(0,1)+1
3240 GOTO 3500
3250 IF A(J,M+1)=A2 THEN L(0,3)=L(0,3)+1
3265 IF A(J,M+1)=A2 THEN L(0,2)=L(0,2)+1
3500 NEXT M
3502 PRINT J;L(0,0);L(0,1);L(0,2);L(0,3)
3505 K=K+1
3520 NEXT J
3850 Z$=""
3900 "NEXT COLOUR ?"
3950 GET Z$: IF Z$="" GOTO 3950
4000 IF A1=3 GOTO 3075
4002 A1=A1+1:GOTO 3075
4005 PRINT "CONTINUE ?"
4100 PRINT: GET Z$: IF Z$="" GOTO 4115
4200 IF Z$="Y" GOTO 1600

```

```

4500 REM STORE PATTERN
4505 PRINT "□"
4507 PRINT "DO YOU WISH TO SAVE THE DESIGN"
4508 GET A$ : IF A$ = "" THEN GOTO 4508
4509 IF A$ = "N" THEN GOTO 1600
4510 PRINT " PREPARE TAPE AND PRESS ANY KEY"
4515 GET A$ : IF A$ = "" GOTO 4515
4520 OPEN 1,1,1
4522 PRINT#1, W
4523 PRINT#1, H
4525 FOR J= 1 TO W-1
4530 FOR M= 1 TO H-1
4535 PRINT#1, A(J,M)
4545 NEXT M
4550 NEXT J
4555 CLOSE 1
4565 GOTO 1600
5000 REM ENTER FROM TAPE
5010 PRINT "□"
5020 PRINT "DO YOU WISH DO LOAD DESIGN FROM TAPE"
5030 GET A$ : IF A$ = "" GOTO 5030
5040 IF A$ = "N" GOTO 1600
5050 PRINT " PREPARE,  LOADS FILE#1 FROM TAPE"
5100 PRINT "PRESS ANY KEY"
5150 GET A$ : IF A$ = "" GOTO 5150
5200 OPEN 1
5210 INPUT#1, W
5220 INPUT#1, H
5250 FOR J = 1 TO W-1
5300 FOR M = 1 TO H-1
5350 INPUT#1, A(J,M)
5400 PRINT A(J,M)
5450 NEXT M
5500 NEXT J
5550 CLOSE 1
5600 PRINT "ENTERED PATTERN"
5650 GOTO 1010

```

Appendix 6

Computer Implementation of Yarn Movement Theory

This appendix presents the basic yarn demand prediction program plus modifications to include rob back, change cam profile and calculate the tension balance point. This program is written in Basic for operation on a Commodore PET microprocessor.

Program Layout

Commencing

Line number

Function

10

Prepare Space

Space is allocated for arrays to store needle selections, crosslink lengths and loop lengths.

650

Machine Information

The gauge, knock over depths on both beds, needle bed separation and number of needles in the repeat are entered from the keyboard.

1350

Enter Needle Selections

Needle selections are entered into the array N(N) with needle 0 as the first needle on the dial, needle 1 the first needle on the cylinder etc. Here even numbered needles are on the dial while odd numbered needles are on the cylinder. N(N) equal to 0 means that needle N doesn't knit and N(N) equal to 1 means needle N knits.

2900

Calculate Crosslink Lengths

By examining the sequence of needle selections for each knitting needle the crosslink length to the next knitting needle is sorted into the four crosslink types and the appropriate length allocated.

- 5250 Calculate Needle Position
- The first and last needles in the knitting zone are found.
- 6600 Calculate Loop Length
- The length of the loops on knitting needles are calculated. Any needle that has left the knitting zone is assumed to hold its maximum length i.e. no rob back occurs. The cylinder and dial needles are isolated so the respective cam depths can be used for calculations.
- 7700 Sum Lengths
- Lengths are summed for loop and crosslink lengths from the first needle in the knitting zone to the first needle which was considered.
- 8050 Calculate Change
- The previous total length is subtracted from the new total length to give the change required and hence the yarn demand.
- 8200 Calculate New Position
- The position of the needles is stepped $1/10$ of a needle space. Here the needles are assumed to maintain a fixed position and the cam position is moved relative to them effectively acting like a rotating cam box machine or a flat bed machine.

Major Variables

N	needle considered
N(N)	selection of needle number N
C(N)	crosslink length of needle number N
L(N)	length of loop on needle number N
G1	needle spacing
KC	knock over depth on cylinder (KOC)
AC	length of cylinder knitting zone
KD	knock over depth on dial (KOD)
A	number of needles in repeat
D1	needle bed separation (D)
M(N)	maximum length held on needle N i.e. when at knock over
MT	total length held in repeat (unit length)
A9	last needle i.e. first needle considered
A8	first needle in knitting zone
LU	previous total length
LT	total length just calculated
LV	length change
L1	start position of section considered
L2	length into section considered

A listing of the program in Basic follows.

```

100 OPEN 1,4
150 REM YM#13
200 PRINT "☐"
250 DIM N(45)
300 DIM L(45)
360 DIM C(45)
400 LT1=0
450 REM LENGTH CALC FOR TWO NEEDLE BEDS
500 REM SUFFIX C FOR CYLINDER NEEDLES
550 REM SUFFIX D FOR DIAL NEEDLES
600 REM BP TO LOWEST NEEDLE
650 REM INPUT INFORMATION
700 INPUT "MACHINE GAUGE NEEDLES/INCH " ;G
750 G1=2.54/G
800 G2=INT((G1*102)+.5)/102
850 INPUT "CYLINDER KO" ;KC
900 AC=KC/(TAN( $\pi/4$ ))
950 INPUT "DIAL KO" ;KD
1000 AD=KD/(TAN( $\pi/4$ ))
1050 INPUT "DIST CYL TO DIAL";D1
1100 REM INPUT NEEDLE SELECTION
1150 INPUT "NO OF NEEDLES IN REPEAT" ;A
1200 IF A=1 THEN PRINT "TWO BEDS?"
1250 IF A=1 GOTO 1150
1300 GOSUB 9200
1350 PRINT "FIRST NEEDLE ON DIAL "
1400 PRINT
1450 PRINT "1-KNIT  0-MISS"
1500 FOR N=0 TO A-1
1550 PRINT "ENTER NEEDLE" N
1600 INPUT AA
1650 B=0
1700 N(N)=AA
1750 IF AA=1 THEN B=1
1800 IF AA=0 THEN B=1
1850 IF B=0 GOTO 1550
1900 NEXT N
1950 PRINT "☐"
2000 PRINT "NEEDLE NO          KNIT/MISS"

```



```

2050 FOR N=0 TO 40
2100 IF N>A-1 THEN N(N)=N(N-(A))
2150 IF N>10 GOTO 2250
2200 PRINT "      "N,"",N(N)
2250 NEXT N
2300 PRINT
2350 PRINT "OK?"
2400 GET Q$: IF Q$="" GOTO 2400
2450 IF Q$="Y" GOTO 2850
2500 PRINT "WHICH NEEDLE IS INCORRECT ?"
2550 INPUT W
2600 PRINT "NEW VALUE FOR "W
2650 INPUT W1
2700 N(W)=W1
2750 IF W1 < 1 AND W1 > 0 GOTO 2600
2800 GOTO 1950
2850 PRINT
2900 REM CROSS LINK CALCULATIONS
2950 REM RIB GATING
3000 L1=D1
3050 L2=((D1)↑2+(G1/2)↑2)↑.5
3100 PRINT "□"
3150 PRINT "NEEDLE","SELECTION      X-LINK"
3200 PRINT 1 "NEEDLE","SELECTION      X-LINK"
3250 FOR N=0 TO 30
3300 IF N(N)<>1 THEN C(N)=0
3350 IF N(N)<>1 THEN GOTO 3900
3400 IF N(N)=N(N+1) THEN C(N)=L1
3450 IF N(N)=N(N+1) THEN GOTO 3900
3500 IF N(N)=N(N+2) THEN C(N)=0
3550 IF N(N)=N(N+2) THEN GOTO 3900
3600 IF N(N)=N(N+3) THEN C(N)=L2
3650 IF N(N)=N(N+3) THEN GOTO 3900
3700 IF N(N)=N(N+4) THEN C(N)=G1
3750 IF N(N)=N(N+4) THEN GOTO 3900
3800 PRINT "UNACCEPTABLE PATTERN"
3850 GOTO 1150
3900 REM PRINT OUT
3950 IF N>(A-1) GOTO 4300

```

```

4000 IF INT(N/2)<>N/2 THEN GOTO 4200
4050 PRINT "    "N" ", "    "N(N),C(N)
4100 PRINT#1,"    "N" ", "    "N(N),C(N)
4150 GOTO 4300
4200 PRINT " "N"    ",N(N),C(N)
4250 PRINT#1 " "N"    ",N(N),C(N)
4300 NEXT N
4350 GET Z$: IF Z$="" GOTO 4350
4400 FOR N=0 TO A-1
4450 IF INT(N/2)=N/2 AND N(N)=1 THEN
            M(N)=2*((G1/2)2+KD2).5
4500 IF INT(N/2)<>N/2 AND N(N)=1 THEN
            M(N)=2*((G1/2)2+KC2).5
4550 MT=MT+M(N)+C(N)
4600 IF C(N)=D1 THEN MT=MT-G1/2
4650 NEXT N
4700 REM CORRECT FOR XL DIFF FROM ST. LENGTH
4750 FOR N=0 TO 30
4800 IF C(N)=L2 THEN C(N)=C(N)-G1/2
4850 IF C(N)=D1 THEN C(N)=C(N)
4900 IF C(N)=G1 THEN C(N)=0
4950 NEXT N
5000 PRINT "TOTAL REPEAT LENGTH =" MT
5050 REM LOOP ON NEEDLE CALCULATION
5100 PRINT "☐"
5150 PRINT "TOTAL LENGTH =" MT
5200 PRINT#1, "TOTAL LENGTH=" MT
5250 REM LAST NEEDLE CALC
5300 L1=(A+10)*G1/2
5350 L8=L1
5400 Q=0
5450 IF AD>=AC THEN Q=1
5500 IF AC>AD THEN Q=2
5550 IF Q=1 THEN LA=L1-AD
5600 IF Q=2 THEN LA=L1-AC
5650 LC=LA
5700 FOR N=0 TO 40
5750 LB=N*G1/2
5800 IF LB>=L1 THEN A9=N

```

```

5850 IF LB =L1 GOTO 5950
5900 NEXT N
5950 PRINT "POSN","LENGTH";" 1ST/LAST "; "LEN CH"
6000 PRINT#1, "POSN","LENGTH";" 1ST/LAST "; "LEN CH"
6050 REM FIRST NEEDLE
6100 LC=LC+G1/10
6150 Q1=0
6200 IF Q=1 THEN LA=L1-AD
6250 IF Q=2 THEN LA=L1-AC
6300 FOR N=0 TO 40
6350 LB=N*G1/2
6400 IF LB>=LA THEN A8=N
6450 IF LB>=LA THEN GOTO 6550
6500 NEXT N
6550 FOR N=A8 TO A9
6600 REM SEPARATE DIAL AND CYL
6650 IF INT(N/2)=N/2 GOTO 7200
6700 REM CYL
6750 IF N(N)=0 THEN L(N)=0
6800 IF N(N)=0 GOTO 7650
6850 IF N*G1/2=<(L1-AC) THEN L(N)=0
6900 IF N*G1/2=<(L1-AC) THEN GOTO 7650
6950 A1=N*G1/2-(L1-AC)
7000 IF A1>AC THEN L(N)=2*((G1/2)2+KC 2).5
7050 IF A1>AC GOTO 7650
7100 L(N)=G1/(SIN(ATN(G1/(2*A1*TAN (π/4)))))
7150 GOTO 7650
7200 REM DIAL
7250 IF N(N)=0 THEN L(N)=0
7300 IF N(N)=0 GOTO 7650
7350 IF N*G1/2=<(L1-AD) THEN L(N)=0
7400 IF N*G1/2=<(L1-AD) GOTO 7650
7450 A1=N*G1/2-(L1-AD)
7500 IF A1>AD THEN L(N)=2*((G1/2)2+KD 2).5
7550 IF A1>AD GOTO 7650
7600 L(N)=G1/(SIN(ATN(G1/(2*A1*TAN (π/4)))))
7650 REM
7700 NEXT N
7750 REM SUM LENGTHS

```



```

7800 LT=LC
7850 FOR N=A8 TO A9
7900 IF L(N)<>0 THEN L(N)=L(N)-G1
7950 LT=LT+L(N)+C(N)
8000 NEXT N
8050 IF LU=0 THEN LU=LT
8100 LV=LT-LU
8150 LU=LT
8200 REM NEXT NEEDLE POSITION
8250 L1=L1-G1/10
8300 X=X+1
8350 IF (L8-L1)>(1+A)*G1/2 THEN GOTO 9000
8400 L2=INT(L1*103+0.5)/103
8450 LT=INT(LT*103+0.5)/103
8500 LV=INT(LV*103+0.5)/103
8550 PRINT L2,LT;A8;A9;LV;
8600 PRINT#1, L2;LT;A8;A9;LV;
8650 IF X=10 GOTO 8750
8700 GOTO 6050
8750 Z$=""
8800 GET Z$: IF Z$="" GOTO 8800
8850 PRINT"NEXT STEP "A8;A9;
8900 X=0
8950 GOTO 6050
9000 PRINT "COMPLETE CYCLE"
9050 PRINT#1, "COMPLETE CYCLE"
9100 CLOSE 1,4
9150 END
9200 REM PRINT OUT
9250 PRINT#1, ""
9300 PRINT#1, "YARN MOVEMENT","YM 13 "
9350 PRINT#1, "-----"
9400 PRINT#1, "GAUGE=" G
9450 PRINT#1, "CYLINDER KO =" KC
9500 PRINT#1, "DIAL KO=" KD
9550 PRINT#1, "DIST CYL TO DIAL =" D1
9600 PRINT#1, "REPEAT =" A
9650 RETURN

```

Introducing Rob Back

To introduce rob back the last needle to have knitted and then left the knitting zone is isolated. This is then assumed to be moving down the cam and so a new length is calculated for this needle. When the lengths are summed they are summed only until they reach knock over (by setting $L(N)$ equal to zero as the needle passes knock over) plus the inclusion of the length of the last needle to have knitted's new length. This then enables additional yarn to enter the knitting zone off this needle.

A new variable A7 is introduced as the last needle to knit which has moved past the knock over point. NP is also introduced as the previous A7 so adjustments can be made when robbing back is off a different needle.

Sections of the original program to calculate needle position, to calculate loop lengths and to sum lengths are changed as follows. These changes are made without altering other line numbers or sections of the program.

```
|
6300 FOR N = 0 TO 40
6350 LB =N * G1/2
6355 IF LB =>L1 AND N(N)=1 THEN A7=N
6360 IF LB =>L1 AND N(N)=1 GOTO 6550
6370 IF Q2 = 1 GOTO 6500
6400 IF LB =>LA THEN A8=N
6450 IF LB =>LA THEN Q2=1
6500 NEXT N
|
```

```

6700 REM    CYL
6850 IF N*G1/2 = < (L1-AC) THEN L(N)=0
6900 IF N*G1/2 = < (L1-AC): GOTO 7650
6950 A1=N*G1/2 -(L1-AC)
6955 IF A7<>NP THEN A1=2*AC-A1
7000 IF A1 > AC AND N=A7 THEN A1=2*AC-A1
7010 IF A1< 0 GOTO 7650
7050 IF A1> AC THEN GOTO 7650
7100 L(N)= G1/(SIN(ATN(G1/(2*A1*TAN( $\pi$ /4))))))
7150 GOTO 7650
7200 REM    DIAL
7350 IF N*G1/2== < (L1-AD) THEN L(N)=0
7400 IF N*G1/2 = < (L1-AD) GOTO 7650
7450 A1 = N*G1/2 - (L1-AD)
7455 IF A7<>NP AND N=NP THEN A1=2*AD-A1
7500 IF A1 > AD AND N=A7 THEN A1=2*AD-A1
7510 IF A1<0 GOTO 7650
7550 IF A1>AD GOTO 7650
7600 L(N) = G1/(SIN(ATN(G1/(2*A1*TAN( $\pi$ /4))))))
7650 REM
7700 NEXT N

8050 IF LU=0 THEN LU=LT
8100 LV=LT-LU
8125 LP=L(A7)
8130 NP=A7
8150 LU=LT

```

Print statements are also altered to print out A7 and L(A7) in addition to the previous variables printed out each time through the loop.

To modify this unrestricted rob back case to the half restricted case the change in $L(A7)$ must be isolated and half this change added back into the system. For calculations in the text this however was carried out manually from printed out $L(A7)$ values for the unrestricted rob back case.

To Modify Cam Shape

The calculate loop length section of the program must be altered to enable modifications to cam shape. Here it is possible to directly enter straight cut cams of any angle (adjusting also the length of the knitting zone). It is also possible to alter the shape of the cam by feeding in the function of needle depth against distance into the knitting zone into the loop calculation section. Previously as the cam is 45° the distance into the knitting zone equals the needle depth. Modifications can also be introduced in the cam shape to effect rob back. Following are program modifications for a cam which has straight cut 45° sides with a half needle space flat on the bottom. Other lines and sections of the unrestricted rob back program are unaltered.

```
6550 FOR N=A8 TO A9
6600 REM SEPARATE DIAL AND CYLINDER
6640 IF N(N)=0 THEN L(N)=0
6645 IF N(N)=0 GOTO 7650
6650 IF INT(N/2)=N/2 GOTO 7200
6670 IF N(N)=0 GOTO 7650
6700 REM CYL
```

```

6850 IF N*G1/2 =< (L1-AC) THEN L(N)=0
6900 IF N*G1/2 =< (L1-AC) GOTO 7650
6950 A1=N*G1/2-(L1-AC)
6955 IF A7<>NP AND N=NP THEN A1=2*AC+G1/2-A1
7000 IF A1>AC+G1/2 AND N=A7 THEN A1=2*AC+G1/2-A1
7005 IF A1>AC+G1/2 AND A1<AC+G1/2 THEN A1=AC
7010 IF A1<0 GOTO 7650
7050 IF A1>AC+G1/2 THEN GOTO 7650
7100 L(N)=G1/(SIN(ATN(G1/2*A1*TAN(PI/4))))
7150 GOTO 7650
7200 REM DIAL
7350 IF N*G1/2=<(L1-AD) THEN L(N)=0
7400 IF N*G1/2=<(L1-AD) GOTO 7650
7450 A1=N*G1/2-(L1-AD)
7455 IF A7<>NP AND N=NP THEN A1=2*AD+G1/2-A1
7500 IF A1>AD+G1/2 AND N=A7 THEN A1=2*AD+G1/2-A1
7505 IF A1>AD AND A1<AD+G1/2 THEN A1=AD
7510 IF A1<0 GOTO 7650
7550 IF A1>AD+G1/2 GOTO 7650
7600 L(N)=G1/(SIN(ATN(G1/2*A1*TAN(PI/4))))
7650 REM
7700 NEXT N

```

To Calculate Angles of Contact and hence Tension Balance

The angles of contact between each loop and the cross link is assumed to be independent of the needle position and so only dependent upon the crosslink type. Angles of contact between the loop arms and the tricks are symmetrical and are calculated depending on needle depth as is the angle of contact between the yarn and the needle.

To calculate the maximum tension and the balance point the theory of section 1.2.2 is used with an input tension of 5 g, a 10 g take-up tension applied on the leg of the

last needle which was knitted and passed the knock over point and a coefficient of friction of 0.2.

An array O(N) is used to store the angles which occur with the loop and O3(N) to store those which occur with the crosslink. The needle O9 closest to the balance point is located and along with the maximum tension (TM) developed and the actual angle into the knitting zone (O4) where tension balance occurs is printed out. Program modifications to achieve this follow.

```
7105 O(N)=ATN(G1/(2*A1*TAN(PI/4)))
```

```
7605 O(N)=ATN(G1/(2*A1*TAN(PI/4)))
```

```
8155 GOSUB 10000
```

```
10000 REM ANGLE CALCULATION
```

```
10010 OT=0
```

```
10015 OO=0
```

```
10020 FOR N=A8 TO A9
```

```
10022 O3(N)=PI/2-O(N)/2
```

```
10023 IF C(N)=L1 THEN O2(N)=0
```

```
10024 IF C(N)=0 THEN O2(N)=2*O3(N)
```

```
10025 IF C(N)=L2 THEN O2(N)=O3(N)
```

```
10026 IF C(N)=G1 THEN O2(N)=2*O3(N)
```

```
10027 IF L(N)=G1 THEN O(N)=PI
```

```
10028 IF L(N)=0 THEN O(N)=PI
```

```
10029 IF L(N)=0 THEN O2(N)=0
```

```
10030 O(N)=-O(N)
```

```
10035 OT=OT+O(N)
```

```
10036 OO=O(N)+OO+O2(N)
```



```

10040 NEXT N
10050 REM BALANCE POINT CALC
10060 O4=1/(2*0.2)*(00*0.2-LOG(5/10))
10070 TM=5*EXP(0.2*O4)
10090 O5=0
10095 O9=0
10100 FOR N=A8 TO A9
10110 O5=O(N)+O5+O2(N)
10120 IF O5<O4 THEN O9=N
10130 NEXT N
10150 RETURN

```

This approach could be developed to make the rob back condition dependent upon the position of the balance point and hence dependent upon the input and take-up conditions as well as the number of needles in the knitting zone.

Appendix 7

Yarn Movement Results - Plain Knit

Demand of yarn, in millimetres, with rotation in steps of a tenth of a needle spacing, is tabulated below for a range of knock over depths on an 18 gge machine.

Needle position	Knock over depth (mm)			
	1.5	2.0	2.5	3.0
<u>No rob back</u>				
1	0.20	0.33	0.38	0.49
2	0.25	0.35	0.39	0.54
3	0.29	0.37	0.41	0.58
4	0.32	0.38	0.47	0.60
5	0.34	0.39	0.52	0.62
6	0.36	0.39	0.56	0.64
7	0.37	0.43	0.59	0.65
8	0.38	0.49	0.61	0.66
9	0.39	0.54	0.63	0.67
10	0.41	0.57	0.64	0.71
<u>Rob back unrestricted from one loop</u>				
1	-0.05	0.07	0.11	0.22
2	0.00	0.09	0.12	0.27
3	0.05	0.11	0.14	0.30
4	0.09	0.12	0.20	0.33
5	0.12	0.13	0.25	0.35
6	0.16	0.15	0.30	0.37
7	0.19	0.20	0.33	0.38
8	0.23	0.26	0.36	0.39
9	0.28	0.32	0.38	0.40
10	0.34	0.38	0.40	0.45

Needle position	Knock over depth (mm)			
	1.5	2.0	2.5	3.0
Rob back restricted to half available off one needle				
1	0.08	0.21	0.25	0.36
2	0.13	0.23	0.26	0.41
3	0.17	0.24	0.27	0.45
4	0.21	0.25	0.34	0.47
5	0.23	0.26	0.38	0.49
6	0.26	0.28	0.43	0.51
7	0.28	0.32	0.46	0.52
8	0.31	0.38	0.49	0.52
9	0.34	0.43	0.50	0.53
10	0.39	0.48	0.52	0.58

Appendix 8

Yarn Movement Model Results - 1x1 Rib

Demand of yarn, in millimetres, with rotation in steps of a tenth of a needle spacing, is tabulated below for a range of knock over depths on an 18 gge machine. All results are for a 1 mm needle bed separation.

Needle position	Knock over depth (mm)			
	1.5	2.0	2.5	3.0

No rob back

1	0.42	1.59	0.80	0.99
2	0.48	0.65	0.84	1.05
3	0.53	0.72	1.88	1.09
4	0.57	0.77	0.94	2.13
5	1.61	0.82	1.02	1.20
6	0.42	1.59	0.80	0.99
7	0.48	0.65	0.84	1.05
8	0.53	0.72	1.88	1.09
9	0.57	0.77	0.94	2.13
10	1.61	0.82	1.02	1.20

Rob back unrestricted from one loop

1	0.17	1.32	0.53	0.72
2	0.23	0.38	0.57	0.78
3	0.29	0.46	1.61	0.82
4	0.34	0.52	0.69	1.86
5	1.39	0.57	0.76	0.93
6	0.17	1.32	0.53	0.72
7	0.23	0.38	0.57	0.78
8	0.29	0.46	1.61	0.82
9	0.34	0.52	0.69	1.86
10	1.39	0.57	0.76	0.93

Appendix 9
Yarn Movement Model†Results - 1000 Unit

Demand of yarn, in millimetres, with rotation in steps of a tenth of a needle spacing, is tabulated below for a range of knock over depths on an 18 gge machine.

Needle position	Knock over depth, KOD (mm)		
	1.5	2.0	2.5
<u>No rob back</u>			
1	0.20	0.33	0.38
2	0.25	0.35	0.39
3	0.29	0.37	0.39
4	0.32	0.38	0.40
5	0.34	0.39	0.40
6	0.36	0.39	0.41
7	0.37	0.40	0.41
8	0.38	0.40	0.41
9	0.39	0.40	0.41
10	0.39	0.41	0.41
11	0.14	0.14	0.14
12	0.14	0.14	0.14
13	0.14	0.14	0.16
14	0.14	0.14	0.21
15	0.14	0.14	0.26
16	0.14	0.14	0.29
17	0.14	0.18	0.32
18	0.14	0.23	0.34
19	0.14	0.27	0.36
20	0.15	0.31	0.37

Needle position	Knock over depth, KOD (mm)		
	1.5	3.0	2.5
	Unrestricted rob back		Half restricted rob back
1	0.20	0.14	0.27
2	0.25	0.15	0.28
3	0.29	0.16	0.29
4	0.32	0.17	0.31
5	0.34	0.18	0.33
6	0.36	0.20	0.35
7	0.37	0.22	0.37
8	0.38	0.24	0.41
9	0.39	0.28	0.41
10	0.39	0.36	0.41
11	-0.11	-0.04	0.01
12	-0.11	0.00	0.01
13	-0.10	0.04	0.02
14	-0.09	0.06	0.08
15	-0.08	0.08	0.12
16	-0.06	0.10	0.16
17	-0.04	0.11	0.20
18	-0.01	0.12	0.22
19	0.03	0.13	0.23
20	0.09	0.14	0.26

Appendix 10

Yarn Movement Model Results - 1100 and 1001 units

Demand of yarn, in millimetres, with rotation in steps of a tenth of a needle spacing, is tabulated below for a range of knock over depths on an 18 gge machine. The needle bed separation is 1 mm in all cases.

Needle position	Knock over depths, KOD=KOC (mm)				
	1.5 No rob back	2.0 back	2.5 unrestricted rob back	3.0 back	2.0 half restricted rob back
1	0.20	1.33	0.27	0.36	0.27
2	0.25	0.39	0.31	0.37	0.27
3	0.29	0.46	0.34	0.39	0.28
4	0.32	0.51	0.37	0.40	0.29
5	1.35	0.55	0.39	0.41	0.42
6	0.42	0.58	0.41	0.42	0.06
7	0.48	0.61	0.44	0.42	0.10
8	0.53	0.63	0.46	0.43	0.15
9	0.57	0.64	0.49	0.97	0.19
10	0.60	0.65	0.52	0.50	1.22
11	0.36	0.39	0.13	0.23	0.27
12	0.37	0.40	0.14	0.28	0.35
13	0.38	0.40	0.67	0.31	0.41
14	0.39	0.40	0.21	1.34	0.46
15	0.39	0.41	0.26	0.40	0.51
16	0.14	0.66	0.03	0.19	0.55
17	0.14	0.18	0.05	0.24	0.59
18	0.14	0.23	1.09	0.28	0.62
19	0.14	0.27	0.16	0.31	0.65
20	0.67	0.31	0.22	0.34	0.26

Half restricted rob back

Needle position	Unit	1001	1100
	KOC (mm)	2.0	2.0
	KOD (mm)	2.5	2.5
1		0.27	0.28
2		0.69	0.70
3		0.34	0.29
4		0.39	0.29
5		0.16	0.01
6		0.20	0.05
7		1.22	1.11
8		0.24	0.21
9		0.25	0.29
10		0.27	0.35
11		0.31	0.41
12		0.38	0.45
13		0.43	0.47
14		0.48	0.51
15		0.53	0.52
16		0.56	0.53
17		0.60	0.55
18		0.63	0.57
19		0.65	0.60
20		0.26	0.27

Appendix 11

Yarn Movement Model Results - 1101 Unit

yarn demand, in millimetres, with rotation in steps of a tenth of a needle spacing, is tabulated below for a range of knock over depths on an 18 gge machine. The needle bed separation is 1 mm in all cases.

Needle position	Knock over depths, KOC=KOD (mm)			
	1.5	2.0	2.5	3.0
	No rob back		unrestricted rob back	
1	0.42	1.59	0.38	0.49
2	0.48	0.65	0.39	0.54
3	0.53	0.72	0.41	0.58
4	0.57	0.77	0.47	1.61
5	1.61	0.82	0.52	0.67
6	0.42	0.58	0.29	0.46
7	0.48	0.61	0.32	0.51
8	0.53	0.63	1.36	0.56
9	0.57	0.64	0.43	1.59
10	0.60	0.65	0.49	0.66
11	0.36	0.39	0.26	0.45
12	0.37	0.43	0.30	0.50
13	0.38	0.49	1.34	0.55
14	0.39	0.54	0.42	0.58
15	0.41	0.57	0.48	0.61
16	0.20	1.33	0.54	0.63
17	0.25	0.39	0.58	0.65
18	0.29	0.46	0.61	0.66
19	0.32	0.51	0.64	0.67
20	1.35	0.55	0.66	0.72

Appendix 12

Yarn Movement Model Results - Combined Units

Yarn demand, in millimetres, with rotation in steps of a tenth of a needle spacing, is tabulated below for two knock over depth combinations. The needle bed separation is 1 mm. All the results are for the unrestricted rob back case.

Needle position	KOC (mm) KOD (mm)	10001101		10011100	
		2.0	2.5	2.0	2.5
		2.0	2.0	2.0	2.0
1		0.17	0.29	0.29	0.06
2		0.23	0.33	-0.08	1.09
3		0.28	1.35	-0.03	0.11
4		0.32	0.38	0.02	0.12
5		1.06	0.39	0.06	0.14
6		0.13	0.13	1.09	0.19
7		0.20	0.16	0.15	1.27
8		0.25	0.22	0.23	0.39
9		0.30	0.27	0.30	0.49
10		0.34	0.31	0.36	0.58
11		0.37	0.34	1.42	0.67
12		0.40	0.36	0.51	0.75
13		0.43	0.38	0.63	0.83
14		0.46	0.40	0.74	0.89
15		0.12	0.42	0.82	0.36
16		0.13	0.11	0.32	0.37
17		0.14	0.13	0.35	0.39
18		0.15	0.13	0.37	0.40
19		0.16	0.14	0.38	0.40
20		-0.12	0.14	0.40	0.12
21		-0.12	-0.13	0.12	0.14
22		-0.12	-0.12	0.13	0.57
23		-0.11	-0.12	0.14	0.16
24		-0.11	-0.11	0.15	0.16

Needle position	KOC (mm) KOD (mm)	10001101		10011100	
		2.0	2.5	2.0	2.5
		2.0	2.0	2.0	2.0
25		-0.10	-0.11	0.16	-0.13
26		-0.06	-0.10	0.29	-0.09
27		0.00	-0.06	-0.08	-0.04
28		0.06	1.02	-0.03	0.01
29		0.12	0.13	0.02	0.04
30		1.17	0.23	0.06	0.07
31		0.26	0.32	0.09	0.09
32		0.37	0.40	0.12	0.11
33		0.47	0.48	0.14	0.13
34		0.55	0.56	0.17	0.14
35		0.58	0.62	0.19	0.16
36		0.61	0.63	0.23	0.18
37		0.63	0.64	0.26	0.63
38		0.64	0.67	0.31	0.29
39		0.65	0.73	0.37	0.37
40		0.13	0.78	0.41	0.04

Appendix 13

Yarn Movement Model Results - Flat Bed

Yarn demand, in millimetres, with cam carriage movement in tenth needle spacing steps, is tabulated below for an 18 gge flat bed machine for the three jacquard units travelling both away and toward the feed side. All results are for the settings KOD = KOC = 2 mm with a needle bed separation of 1 mm for the no rob back case.

Needle position	Away			Toward		
	1000	1001	1101	1000	1001	1101
1	0.47	1.47	1.73	0.19	1.19	1.45
2	0.49	0.53	0.79	0.21	0.25	0.51
3	0.51	0.60	0.86	0.23	0.32	0.58
4	0.52	0.65	0.91	0.24	0.37	0.63
5	0.53	0.69	0.96	0.25	0.41	0.68
6	0.53	0.72	0.72	0.25	0.44	0.44
7	0.54	0.75	0.75	0.26	0.47	0.47
8	0.54	0.77	0.77	0.26	0.49	0.49
9	0.54	0.78	0.78	0.26	0.50	0.50
10	0.55	0.79	0.79	0.27	0.51	0.51
11	0.28	0.53	0.53	0.00	0.25	0.25
12	0.28	0.54	0.57	0.00	0.26	0.29
13	0.28	0.54	0.63	0.00	0.26	0.35
14	0.28	0.54	0.68	0.00	0.26	0.40
15	0.28	0.55	0.71	0.00	0.27	0.43
16	0.28	0.80	1.47	0.00	0.52	1.19
17	0.32	0.32	0.53	0.04	0.04	0.25
18	0.37	0.37	0.60	0.09	0.09	0.32
19	0.41	0.41	0.65	0.13	0.13	0.37
20	0.45	0.45	0.69	0.17	0.17	0.41

Appendix 14

Microprocessor Translation and Step Presentation Program

This program, from the number and direction of steps which are fed via the keyboard, translates the steps into the required format to drive a four phase stepper motor directly from four output lines. External switching will be required for the motor coils.

The program is written in Basic for a Commodore PET microprocessor. The following sequence is the stepping required on the first 4 bits of the output port.

2^0	2^1	2^2	2^4	decimal
1	0	1	0	5
0	1	1	0	6
0	1	0	1	10
1	0	0	1	9

Presenting this sequence in the order shown rotates the motor shaft clockwise while presenting the sequence in the reverse order results in counter clockwise rotation.

Variables used are :

- Q number of steps required , +ve for
 clockwise, -ve for counter clockwise
- P internal counter
- A 4 bit number to be presented to output
 port

System locations are :

- 59459 control of direction of port A lines
- 59471 output port A

A listing in Basic follows

```
5      POKE (59459),255 : REM SET LINES AS OUTPUT
15     POKE (59471),5 : REM TURN ON POSITION
25     INPUT "HOW MANY STEPS"; Q
35     P = 0 : REM SET COUNTER
40     REM STEP DELIVERY LOOP
45     A = PEEK(59459) : REM PREVIOUS STEP
55     IF Q < 0 GOTO 145
60     REM CLOCKWISE
65     IF A = 5 GOTO 105
75     IF A = 6 GOTO 115
85     IF A = 10 GOTO 125
95     A = 5 : GOTO 135
105    A = 6 : GOTO 135
115    A = 10 : GOTO 135
125    A = 9
135    P = P + 1
140    GOTO 220
145    REM COUNTER CLOCKWISE
150    IF A = 9 GOTO 185
155    IF A = 10 GOTO 195
165    IF A = 6 GOTO 205
175    A = 5 : GOTO 215
185    A = 10 : GOTO 215
195    A = 6 : GOTO 215
205    A = 5
215    P = P - 1
220    REM STEP
230    POKE (59471),A
250    IF P < > Q GOTO 45
260    PRINT "ANOTHER MOVE?"
270    GET A$ : IF A$ = "" GOTO 270
300    IF A$ = "Y" GOTO 25
400    END
```

Appendix 15

Control of Number and Frequency of Pulse Delivery by Parallel In, Serial Out Facilities on the Mircoprocessor

A machine code program with a disassembled version is given to read frequency and duration of delivery from a table and control this as a pulse delivered on the CB2 line. The program is entered by SYS(6416) with 6416 being the decimal location of the program (Hexadecimal 1910). The following system locations are given in hexadecimal form.

ACR E84B

SR E84A

TIM2 E848

Variables used and their locations are as follows.

YTEMP 1900 used for temporary storage

TEMPO 1901 used for control of breaks between
 pulse group deliveries

A machine code listing with a disassembled form follows.

19 10	A9 10	set up	LDA 10
19 12	8D 4B E8		STA ACR
19 15	A9 F0		LDA F0
19 17	8D 4A E8		STA SR
19 1A	A0 00		LDY 0 loop to here to reset
19 1C	B9 00 1A	get freq	LDA freq,Y
19 1F	8D 48 E8		STA TIM2
19 22	F0 20		BEQ END
19 24	C8		INY
19 25	B9 00 1A	get dur	LDA dur,Y
19 28	C8		INY
19 29	AA	dur	TAX

19 2A	8C 00 19		STY YTEMP
19 2D	A9 03	loop	LDA 03 adjust for TEMPO
19 2F	8D 01 19		STA TEMPO
19 32	A0 FB	loop 1	LDY FB
19 34	88	loop 2	DEY
19 35	D0 FD		BNE loop 2
19 37	CE 01 19		DEC TEMPO
19 40	D0 F6		BNE loop 1
19 42	CA		DEX
19 43	D0 EE		BNE loop
19 3F	AC 00 19	restore	LDY YTEMP
19 42	D0 D8		BNE get freq
19 44	A9 00	end	LDA 0
19 46	8D 4A E8		STA ACR
19 49	8D 4A E8		STA SR
19 4C	8D 48 E8		STA TIM2
19 4F	60		RTS
1A 00			table laid out freq 1,dur:1, freq 2, etc zeros at end

Appendix 16

Single Motor Microprocessor Control

A program in Basic follows which passes the number of pulses to be delivered via the USR function. The position pointers in locations 1 and 2 give the position of the machine code program.

```
10  POKE 1,58 : POKE 2,3
20  INPUT "INDEX X" ; X
30  W = USR(X)
40  END
```

The machine code program to control the stepper motor through closed loop control on the 555 oscillator to deliver X pulses and a disassembled version of the program follow. System locations and the program are given in hexadecimal notation.

Location

62	Index low order
61	Index high order
60	Acceleration low order
59	Acceleration high order
63	Slow flag
E84F	Port A
E84E	IER control register
E84B	ACR timer control
E84C	PCR control register
E846	TCL timer
E845	TCH timer
E84D	IFR pulse flag
E843	DDRA data direction control
D09A	Integer to floating point

Location

03F5 Timer low order
03F6 Timer high order

Program

03 3A	20 9A D0		JSR D09A floating point to int.
03 3D	78		SEI
03 3E	A0 FF		LDY #FF
03 40	8C 43 E8		STY E843
03 43	A9 00		LDA #00
03 45	8D 4F E8		STA E84F port A outputs low
03 48	A9 C0		LDA #C0
03 4A	85 63		STA 63
03 4C	A5 61		LDA 61
03 4E	10 16		BPL 0366 +ve index
03 50	A9 08		LDA #08
03 52	8D 4F E8		STA E84F set -ve flag
03 55	98		TYA
03 56	45 62		EOR 62
03 58	18		CLC
03 59	69 01		ADC #01
03 5B	85 62		STA 62
03 5D	98	+ve	TYA
03 5E	45 61		EOR 61
03 60	90 02		BCC 0364
03 62	69 00		ADC #00
03 64	85 61		STA 61
03 66	A5 62		LDA 62
03 68	85 60		STA 60
03 6A	A5 61		LDA 61
03 6C	85 5F		STA 5F
03 6E	D0 0F		BNE 037F large index
03 70	A5 62		LDA 62
03 72	D0 03		BNE 0377 not zero to cont.
03 74	4C DE 03		JMP 03DE
03 77	C9 50	cont	CMP #50
03 79	B0 04		BCS 037F index > 80

03 7B	A9 40		LDA #40
03 7D	85 63	>80	STA 63 Slow only flag
03 7F	AD 4C E8		LDA E84C
03 82	09 01		ORA #01
03 84	8D 4C E8		STA E84C CA1 +ve edge
03 87	AD 4B E8		LDA E84B
03 8A	29 3F		AND #3F
03 8C	8D 4B E8		STA E84B mono timer
03 8F	AD F5 03		LDA 03F5
03 92	8D 46 E8		STA E846
03 95	AD F6 03		LDA 03F6
03 98	8D 45 E8		STA E845
03 9B	AD 4F E8		LDA E84F
03 9E	05 63		ORA 63
03 A0	8D 4F E8		STA E84F start index
03 A3	A9 02	start	LDA #02
03 A5	8D 4D E8		STA E84D
03 A8	2C 4D E8	loop 1	BIT E84D
03 AB	F0 FB		BEQ 03A8 test pulse loop 1
03 AD	A6 62		LDX 62
03 AF	D0 02		BNE 03B3 low order index not 0
03 B1	C6 61		DEC 61 dec. index high order
03 B3	C6 62		DEC 62 dec. index low order
03 B5	D0 04		BNE 03BB
03 B7	A5 61		LDA 61
03 B9	F0 23		BEQ 03DE finish
03 BB	AD 4F E8		LDA E84F
03 BE	29 80		AND #80
03 C0	10 E1		BPL 03A3
03 C2	A9 40		LDA #40
03 C4	2C 4D E8		BIT E84D
03 C7	70 05		BVS 03CE accel. time over
03 C9	20 E8 03		JSR 03E8 dec. accel.
03 CC	F0 05		BEQ 03D3
03 CE	20 E8 03		JSR 03E8
03 D1	D0 D0		BNE 03A3
03 D3	AD 4F E8		LDA E84F
03 D6	29 7F		AND #7F
03 D8	8D 4F E8		STA E84F F off
03 DB	4C A3 03		JMP 03A3 to start

03 DE	AD 4F E8	finish	LDA E84F
03 E1	29 3F		AND #3F
03 E3	8D 4F E8		STA E84F F and S off
03 E6	58		CLI
03 E7	60		RTS
03 E8	A6 60		LDX 60
03 EA	D0 02		BNE 03EE
03 EC	C6 5F		DEC 5F
03 EE	C6 60		DEC 60
03 F0	D0 02		BNE 03F4
03 F2	A5 5F		LDA 5F
03 F4	60		RTS
03 F5	FF		Timer set positions
03 F6	7F		

Appendix 17

Dual Motor Microprocessor Control

A program in Basic is used to pass X and Y indices as 8 bit integers into "post boxes". Locations of these positions are 6436 to 6441 (Hex 1926 to Hex 1929). The direction line is also set from this program. SYS(6144) enters the machine code program.

```
10  INPUT "INDEX X" ; X
20  INPUT "INDEX Y" ; Y
30  GOSUB 3000

3000 AX% = ABS(X) : XH% = AX%/256 : XL% = AX% AND 255
3010 AY% = ABS(Y) : YH% = AY%/256 : YL% = AY% AND 255
3020 IF SGN(X) = -1 THEN S = S OR 8
3030 IF SGN(Y) = -1 THEN S = S OR 4
3040 POKE 84,S
3050 POKE 6438,XL%
3060 POKE 6439,XH%
3070 POKE 6440,XL%
3080 POKE 6441,YH%
4000 SYS(6144) : RETURN
```

A machine code program to simultaneously control two motors; one to deliver X pulses and the other Y pulses, follows with a disassembled version of the program. The system locations and the program are given in hexadecimal notation.

Location

54	Slow only flags
55	accel X high
56	accel X low

Location

57	index X high
58	index X low
59	accel Y high
60	accel Y low
61	index Y high
62	index Y low
E84F	port A
E84E	IER control register
E84B	ACR control register
E84C	PCR control register
E846	TCL timer
E845	TCH timer
E84D	IFR pulse in
E843	DDRA data direction control
1924	timer low
1925	timer high

Program

18 00	78	SEI
18 01	A0 FF	LDY #FF
18 03	8C 43 E8	STY E843
18 06	A9 00	LDA #00
18 08	8D 4F E8	STA E84F , port A outputs low
18 0B	A5 54	LDA 54
18 0D	09 F0	ORA #F0
18 0F	85 54	STA 54 X & Y , F & S on
18 11	AD 27 19	LDA 1926
18 14	85 58	STA 58
18 16	85 56	STA 56
18 18	AD 27 19	LDA 1927
18 1B	85 57	STA 57
18 1D	85 55	STA 55
18 1F	D0 16	BNE 1837 large index
18 21	A5 58	LDA 58
18 23	D0 08	BNE 182D index not zero
18 25	A5 54	LDA 54
18 27	29 3F	AND #3F

18 29	85 54		STA 54 zero index
18 2B	D0 0A		BNE 1837
18 2D	C9 50	cont	CMP #50
18 2F	B0 06		BCS 1837 >80 index Y ind
18 31	A5 54		STA 54
18 33	29 7F		AND #7F no fast
18 35	85 54		STA 54
18 37	AD 28 19	Y ind	LDA 1928
18 3A	85 5C		STA 5C
18 3C	85 5A		STA 5A
18 3E	AD 29 19		LDA 1929
18 41	85 5B		STA 5B
18 43	85 59		STA 59
18 45	D0 1D		BNE 18 64
18 47	A5 5C		LDA 5C
18 49	D0 0F		BNE 18 5A not zero index pls
18 4B	A5 54		LDA 54
18 4D	29 CF		AND #CF
18 4F	85 54		STA 54
18 51	29 C0		AND #C0
18 53	D0 03		BNE 1858 X not zero pl
18 55	4C 15 19		JMP 1915 both zero finish
18 58	A5 5C	pl	LDA 5C
18 5A	C9 50	pls	CMP #50
18 5C	B0 06		BCS 1864 >80 index
18 5E	A5 54		LDA 54
18 60	29 DF		AND #DF
18 62	85 54		STA 54
18 64	AD 4C E8	>80	LDA E84C
18 67	09 11		ORA #11 CA1, CB1 & edge
18 69	8D 4C E8		STA E84C
18 6C	AD 4B E8		LDA E84C
18 6F	29 3F		AND #3F
18 71	8D 4B E8		STA E84B
18 74	AD 24 19		LDA 1924
18 77	8D 46 E8		STA E846
18 7A	AD 25 19		LDA 1925
18 7D	8D 45 E8		STA E845
18 80	AD 4F E8		LDA E84F

18 83	05 54		ORA 54	
18 85	8D AF E8		STA E84F	start indexing
18 88	A9 12	start	LDA #12	
18 8A	8D 4D E8		STA E84D	
18 8D	A9 12	loop 1	LDA #12	
18 8F	2C 4D E8	loop 2	BIT E84D	pulse ?
18 92	F0 FB		BEQ 188F	loop 2
18 94	AD 4D E8		LDA E84D	
18 97	29 02		AND #02	
18 99	F0 2F		BEQ 18CA	Y pulse
18 9B	8D 4D E8		STA E84D	
18 9E	A2 04		LDX #04	
18 A0	20 17 19		JSR 1917	dec X
18 A3	F0 56		BEQ 18FB	X over, fin X
18 A5	A2 02		LDX #02	
18 A7	AD 4F E8		LDA E84F	
18 AA	29 80		AND #80	
18 AC	10 DF		BPL 188D	no fast, loop 1
18 AE	A9 40		LDA #40	
18 B0	2C 4D E8		BIT E84D	
18 B3	70 05		BVS 18BA	acc. over
18 B5	20 17 19		JSR 1917	dec acc
18 B8	F0 05		BEQ 18BF	half way
18 BA	20 17 19	acc over	JSR 1917	
18 BD	D0 CE		BNE 188D	next, loop 1
18 BF	AD 4F E8	no fast	LDA E84F	
18 C2	29 7F		AND #7F	
18 C4	8D 4F E8		STA E84F	fast off
18 C7	4C 8D 18		JMP 188D	loop 1
18 CA	A9 10	Y pulse	LDA #10	Y index
18 CC	8D 4D E8		STA E84D	
18 CF	A2 08		LDX #08	
18 D1	20 17 19		JSR 1917	dec Y
18 D4	F0 34		BEQ 190A	Y over, fin Y
18 D6	A2 06		LDX #06	
18 D8	AD 4F E8		LDA E84F	
18 DB	29 20		AND #20	
18 DD	F0 AE		BEQ 188D	no fast, loop 1
18 DF	A9 40		LDA #40	

18 E1	2C 4D E8		BIT E84D	
18 E4	70 05		BVS 18EB	acc. over
18 E6	20 17 19		JSR 1917	dec acc
18 E9	F0 05		BEQ 18F0	half way
18 EB	20 17 19	acc over	JSR 1917	
18 EE	D0 9D		BNE 188D	next, loop 1
18 F0	AD 4F E8		LDA E84F	
18 F3	29 DF		AND #DF	
18 F5	8D 4F E8		STA E84F	Fast off
18 F8	4C 8D 18		JMP 188D	next, loop 1, end X
18 FB	AD 4F E8	fin X	LDA E84F	
18 FE	29 3F		AND #3F	F & S off
19 00	8D 4F E8		STA E84F	
19 03	29 F0	test	AND #F0	
19 05	F0 0E		BEQ 1915	both over, finish
19 07	4C 8D 18		JMP 188D	loop 1, end Y
19 0A	AD 4F E8	fin Y	LDA E84F	
19 0D	29 CF		AND #CF	
19 0F	8D 4F E8		STA E84F	F & S off
19 12	4C 03 19		JMP 1903	all over ? test
19 15	58	finish	CLI	
19 16	60		RTS	
19 17	B5 54		LDA 54,X	
19 19	D0 02		BNE 191D	
19 1B	D6 53		DEC 53,X	
19 1D	D6 54		DEC 54,X	
19 1F	D0 02		BNE 1923	
19 21	B5 53		LDA 53,X	
19 23	60		RTS	
19 24	FF			Timer set positions
19 25	7F			

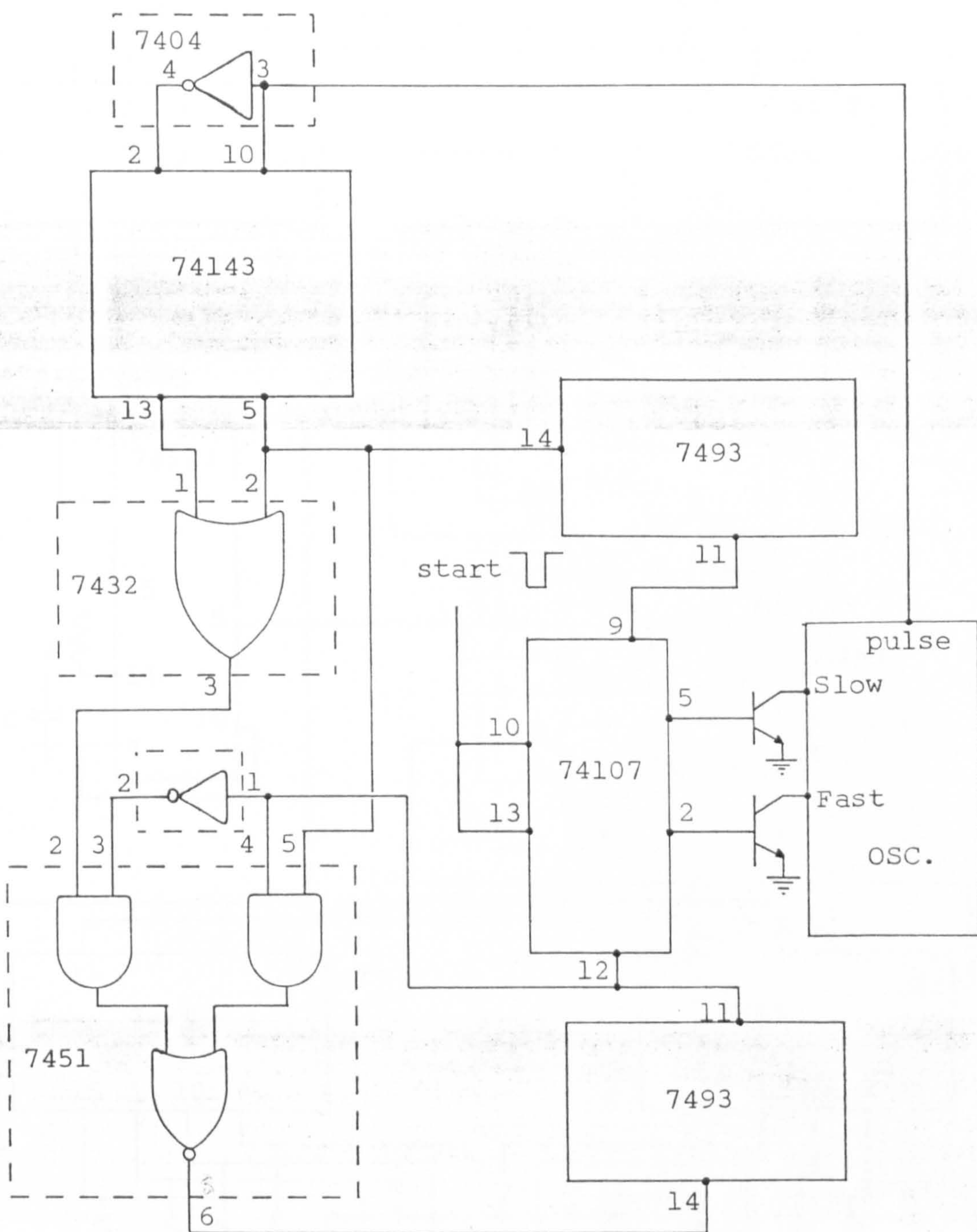
Appendix 18

Hardware Duplication of Microprocessor Control System

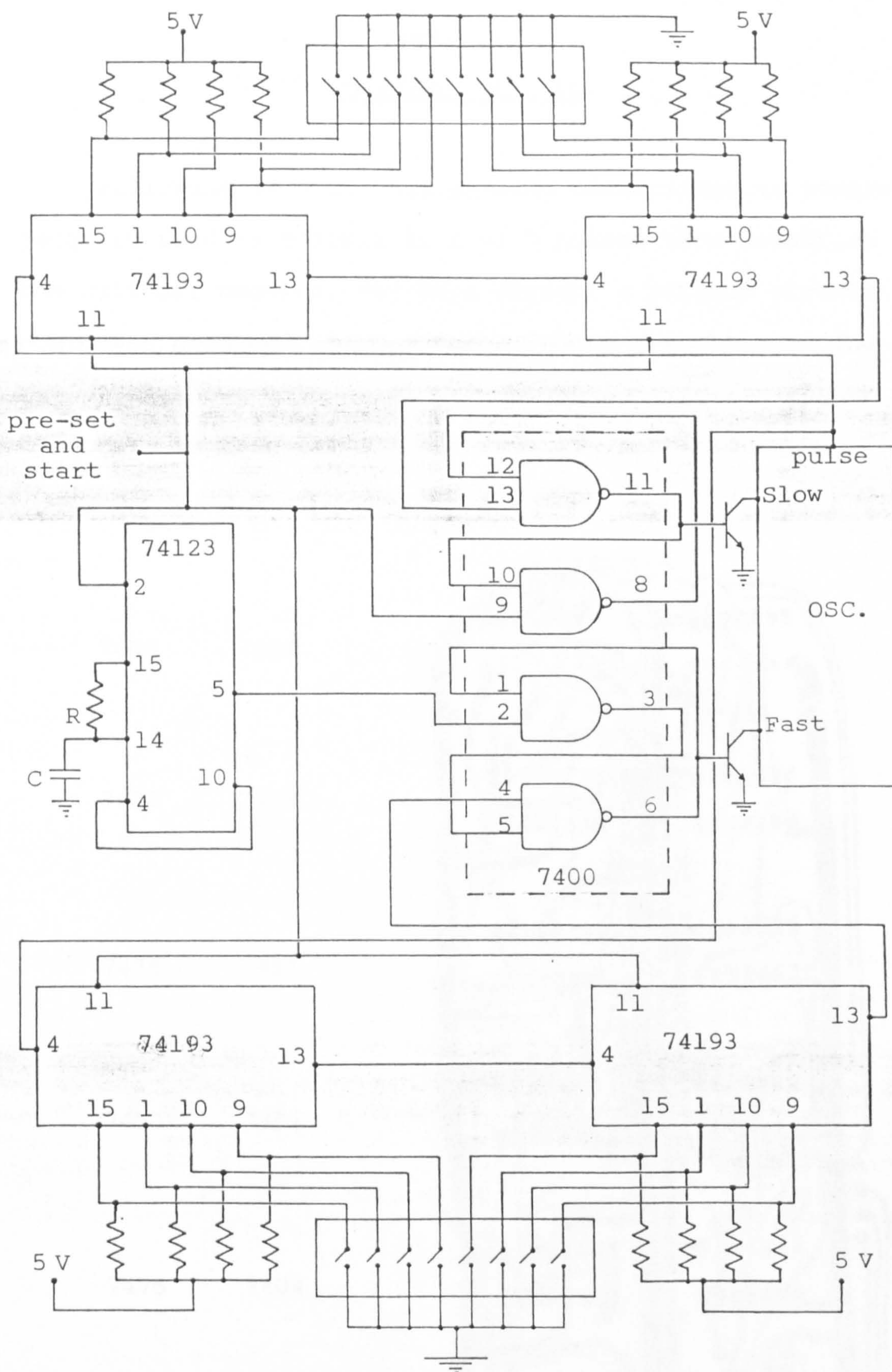
On the following pages are two circuits which can be used to control the stepper motor through a closed loop on the 555 ramped oscillator.

The first circuit uses a frequency doubler based on using the dual monostable 74123. The circuit as shown is set to give 16 pulses; 12 with Fast on.

The second circuit uses 8 bit counters pre-set by switches to determine the number of pulses delivered with Fast and Slow on.



Circuit using frequency doubler

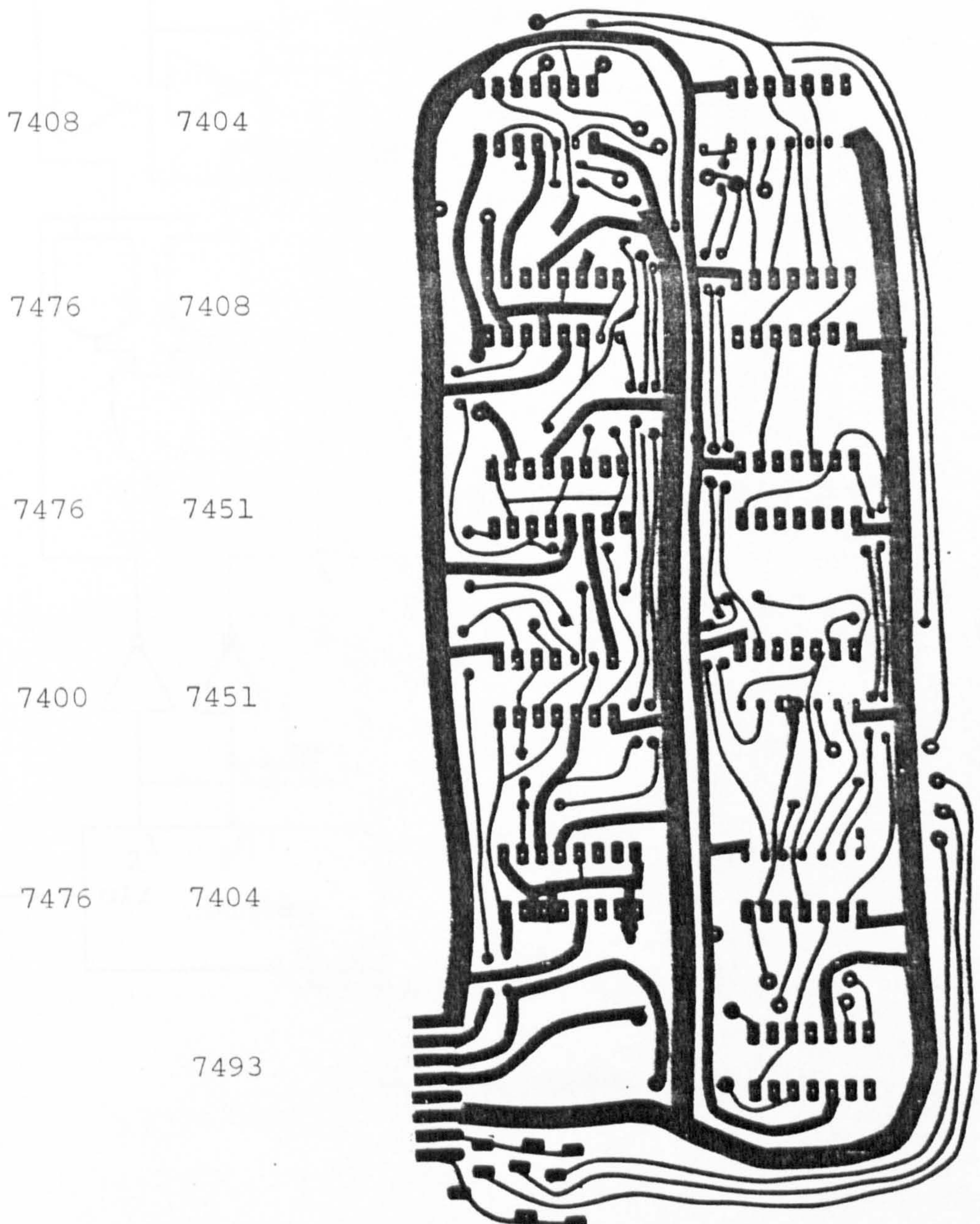


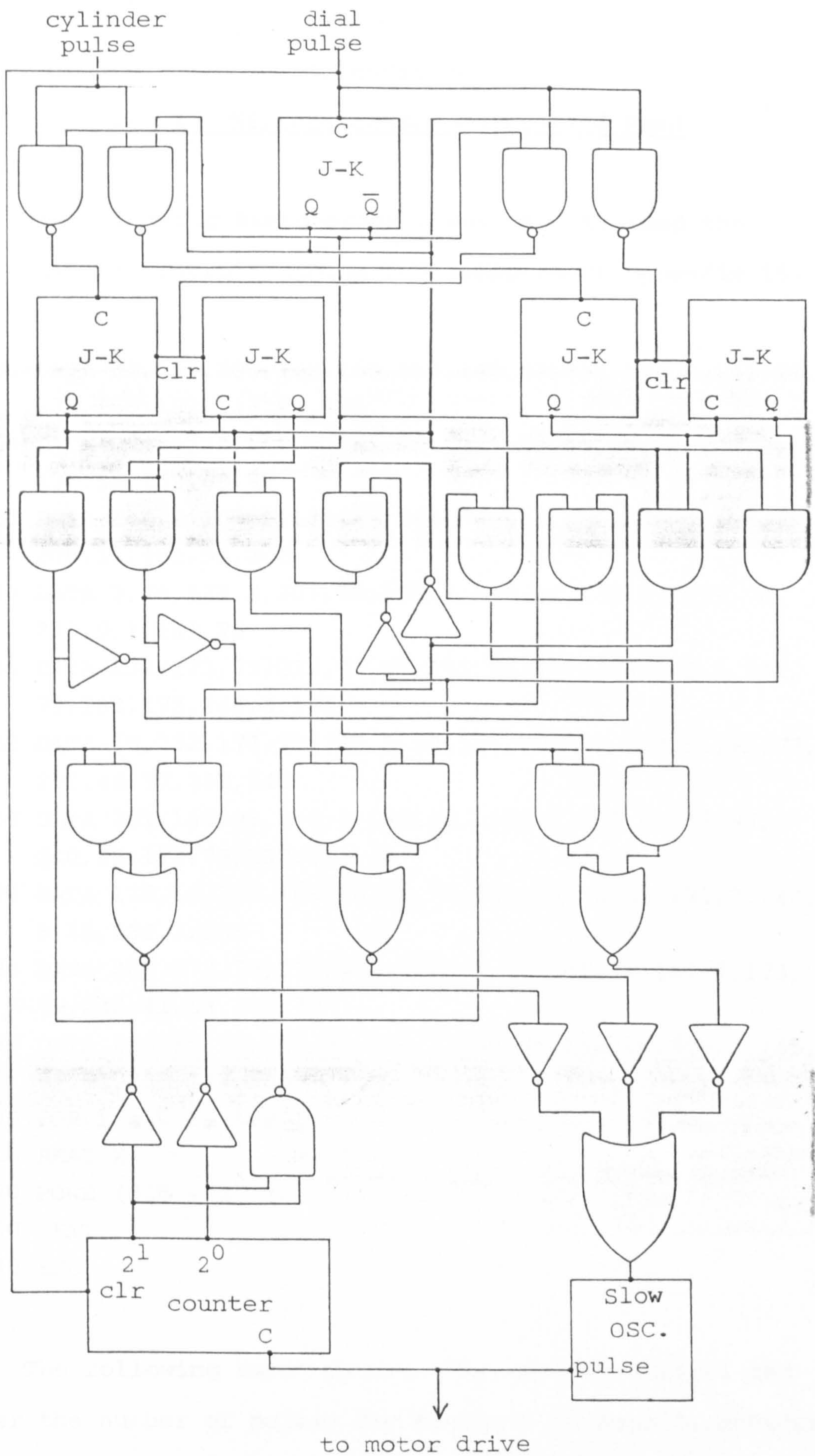
Circuit using pre-settable counters

Appendix 19

Toggling Circuit

Following is a circuit showing connections to control jacquard feed to deliver 1, 2 or 3 pulses from detection of the cylinder needles. For this circuit a printed circuit board was produced using a copper etching technique. The layout is shown below from the component side (as though the board is transparent) with the TTL packages used.





Appendix 20

Flat Bed Microprocessor Controlled Feed

The following Basic program was used to load the single motor control machine code program of Appendix 16.

```
21000 DATA 32,154,208,120,160,255,140,67,232,169,0,141,79,
        232,169,192,133,99,165
21010 DATA 97,16,22,169,8,141,79,232,152,69,98,24,105,1,
        133,98,152,69,97
21020 DATA 144,2,105,0,133,97,165,98,133,96,165,97,133,95,
        208,15,165,98,208
21030 DATA 3,76,222,3,201,80,176,4,169,64,133,99,173,76,
        232,9,1,141,76
21040 DATA 232,173,75,232,41,63,141,75,232,173,245,3,141,
        70,232,173,246,3,141
21050 DATA 69,232,173,79,232,5,99,141,79,232,169,2,141,77,
        232,44,77,232,240
21060 DATA 251,166,98,208,2,198,97,198,98,208,4,165,97,
        240,35,173,79,232,41
21070 DATA 128,16,225,169,64,44,77,232,112,5,32,232,3,240,
        5,32,232,3,208
21080 DATA 208,173,79,232,41,127,141,79,232,76,163,3,173,
        79,232,41,63,141,79
21090 DATA 232,88,96,166,96,208,2,198,95,198,96,208,2,165,
        95,96,255,127,208
30000 FOR I = 0 TO 189
30010 READ X
30020 POKE (826 + I),X
30030 NEXT
30040 END
```

The following Basic program was used to control and enter the number of pulses for movement in both directions, setting speed in each direction, operated off a switch on line 0 (PEEK(5971) AND 1). A count to 100 through the "Q"

loop is used to delay the switching past the second edge switch.

```
10 POKE 1,58 : POKE 2,3
20 INPUT "R---L LENGTH" ; X
30 INPUT " L---R LENGTH" ; Y
24 POKE 59459,254
25 IF PEEK (59471) AND 1 THEN 27
26 GOTO 25
27 PRINT "R---L" X "PULSES"
29 POKE 841,192
30 W = USR(X)
35 PRINT : PRINT "WAITING"
40 FOR Q = 1 TO 100 : NEXT Q
43 POKE 59459,254
45 IF PEEK (59471) AND 1 THEN 50
46 GOTO 45
50 PRINT "L---R" Y "PULSES"
56 POKE 841,64
60 W = USR(Y)
61 FOR Q = 1 TO 100 : NEXT Q
62 PRINT : PRINT "WAITING"
63 POKE 59459,254
65 IF PEEK (59471) AND 1 THEN 27
66 GOTO 65
```

Appendix 21

Proposed Flat Bed Feed Control Circuit

The following circuit uses a programmable ROM to store feed data to give four pre-settable lengths and speeds with the cam carriage moving in either direction. The pre-set lengths can be up to 256 steps.

